NASA CR-66116

A Study Of Man's Physical Capabilities On The Moon

VOLUME I, PART 2

INSTRUMENTATION

By F. Larmie

Prepared under Contract No. NAS 1-4449 by
NORTHROP SPACE LABORATORIES
3401 West Broadway
Hawthorne, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A STUDY OF MAN'S PHYSICAL CAPABILITIES

ON THE MOON

ABSTRACT

A study was made to compare man's energy expenditure and gait characteristics, during self locomotion at various rates, in earth and in simulated lunar gravity conditions. The tests were made for the subject walking and running on the level and on grades up to 30° while in shirt sleeves and while wearing a suit pressurized to 3.5 psig. The results, presented in four volumes, may be useful for the design of space suits and life support systems and the planning of lunar exploration missions and their logistics.

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FOREWORD

This report was prepared by Northrop Space Laboratories (NSL), Hawthorne, California and describes the instrumentation used in support of NASA Contract NAS 1-4449 entitled "A Study of Man's Physical Capabilities on the Moon." This program was administered by Langley Research Center with Mr. W. Letko as NASA Technical Monitor.

The study reported herein was performed by Northrop Space Laboratories in association with Case Institute of Technology, Cleveland, Ohio. Dr. Walter Kuehnegger served as Principal Investigator for NSL. Professor James B. Reswick, Director of the Case Institute Engineering Design Center, guided and directed the work conducted at Case under subcontract.

In view of the complexity and scope of the work performed under this contract, the final report has been organized in four separate volumes (numbered I thru IV). Since the work itself was broken down into phases it was possible to treat each phase individually and document them correspondingly. The four volumes which comprise this report are identified as follows.

CR-66115	Volume I, Part 1 - Lunar Gravity Simulation Facility
CR-66116	Volume I, Part 2 - Instrumentation
CR-66117	Volume II, Part 1 - Biomechanics Research Program
CR-66118	Volume II, Part 2 - Biomechanics Research Program Appendixes
CR-66119	Volume III - Work Physiology Research Program
CR-66120	Volume IV - Investigation of Lunar Gravity Simulation Techniques

Volumes I thru III were produced by NSL and have been assigned Northrop Space Laboratories' document number NSL 65-153. Volume IV was prepared from material contributed by Case Institute and reports on their portion of the contract effort. The total report (all four volumes) summarizes the performance during the contract period from 2 November 1964 to 30 September 1966.

The author of this report (Volume I, Part 2) wishes to express appreciation to Dr. Kuehnegger for the opportunity and responsibility to perform the engineering and supervision of the instrumentation and bioinstrumentation systems. Special gratitude is expressed to Mr. J. Schuessler for his persistent and tireless effort in making the instrumentation systems a reality. Many other members of Northrop Corporation, too numerous to mention, also made valuable contributions to this task.

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A STUDY OF MAN'S PHYSICAL CAPABILITIES ON THE MOON

VOLUME I. PART 2 - INSTRUMENTATION

by F. Larmie
Northrop Space Laboratories

SUMMARY

The instrumentation system described in this report was assembled primarily from equipment owned by Northrop Space Laboratories. Only the communication network components, along with some smaller pieces of equipment were purchased under the contract. The system was constructed around an eight channel biomedical strip chart recorder, a four channel magnetic tape recorder, a D.C. power supply, and a thermistor temperature indicator. Since there were many variables to be monitored at the subject while he was performing on the lunar gravity simulator, and because of the need for a suit pressurization line, a hard wire umbilical was used. This umbilical was tied into a back pack which was carried by the subject and which served as a mounting platform for the respirometer, electrical box, communications preamplifier, and respiration rate detector (Instrument Pack I), and the ECS system used on Instrument Pack II.

The physiological variables monitored were body temperatures, heart rate, and respiration rate. The remaining variables monitored were the ECS temperatures, expired air temperature, globe thermometer temperature, and suit pressure. A voice communications network existed between the subject and all the important test monitor stations.

The system has functioned successfully to date in obtaining the test information desired. With this system, contract cost was held to a minimum without sacrificing reliability. As maybe expected, minor problems arose from time to time; however, they were easily solved by simple alterations in technique.

INTRODUCTION

Instrumentation requirements for this study were dictated primarily by the physiological information needed to determine the metabolic levels of subjects performing various tasks in either a shirt sleeve or pressure suit mode. The subject's need for a pressurization line while in a full pressure suit, the number of data sources to be monitored, and economic considerations indicated a hard wire system would be preferable to the use of telemetry.

Some of the anticipated problems of a hard wire umbilical over extended distances were pickup and transmission of the ECG signal, error introduced into temperature readings by the cable, and voice transmission. By proper signal conditioning with small preamplifiers at the subject, and by the use of the maximum allowable wire size consistent with flexibility, these problems were effectively reduced.

Most of the techniques used to obtain information were compatible with the current state of the art. In some cases, however, an attempt was made to develop special instrumentation which might have decided advantages over available hardware. The overall instrumentation philosophy followed from the start of the contract was one of simplicity in design and development. The result was the fabrication of a reliable instrumentation system in an optimum period of time.

A simplified flow of information throughout the system during a normal testing run is presented in Figure 1. The information flow depicted is in a dynamic form and does not include the biomechanical data acquired by the photographer. The biomechanical data is thoroughly discussed in Volume II of this report. The intelligence flowing toward the test director is presented visually and recorded in two different ways. The complete system block diagram (Figure 2) reveals in greater detail the methods used to handle this information.

INSTRUMENTATION METHODS

System

Figure 2 is a block diagram of the complete system and indicates the data flow paths from the subject to the display and recording equipment. The data source consisted of the subject and the associated transducers used to sense the indicated variables. This information was then channeled into the electrical junction box on the subject's back pack, conditioned, and transferred via the electrical umbilical into the test control center where it was displayed and recorded as indicated. The system components will be discussed separately in the sections that follow.

Bioinstrumentation

Harness. - In the early stages of the program it became apparent that the wiring to the eleven temperature sensors and three ECG electrodes from the abdominal connector would be a continual problem unless channeled together in an orderly fashion. The harness for anchoring these leads evolved from continuous experimentation and is shown in Figures 3, 4, and 5. The harness was constructed of type I Dacron webbing, MIL Spec. MIL-W-25361 (USAF) and was fastened by Velcro at the non-sewn attachment points. The two shoulder straps were sewn together where they crossed over the sternum and were sewn into the subject's waist belt in the front. To don the harness, the subject walked forward with extended arms into the harness held by an assistant. The shoulder straps were then crossed and fastened over his lower back, where they were fastened to the waist strap, not shown crossed in Figure 5 so that the common ECG electrode and thermistor can be seen. The attachment of the ECG electrodes and skin thermistors to the subject then proceeded. Small loops, accommodating the leads to the various biosensors, were sewn on all three straps. These leads terminated in a flat subminiature 37-pin abdominal connector which was held to the waist strap by means of Velcro. A short subject cable was mated to the abdominal connector and passed through the subject's flight suit to be connected to the electrical junction box. A similar cable was installed through a pressurization port on the full pressure suit (see Figure 6) and potted into a matching connector. This system made it possible to use the same harness and electrical box for either a shirt sleeve or full pressure suit test run.

Standard thermistors were used to sense subject skin temperatures and deep core temperature. The leads from the skin sensors were connected directly to the abdominal connector, whereas the internal temperature sensor lead was interrupted by a small two conductor coaxial cable connector. This feature allowed interchangeability of the harness with different subjects while allowing each subject to have an individual deep core temperature probe.

The first ECG electrodes used were the Mercury ECG flight type but later a change was made to the newer biopotential skin electrodes. The electrode leads were kept relatively short and each terminated in a pin which attached to a connector which, in turn, wired into the abdominal connector. The three electrode leads from their connectors formed part of the wiring in the harness, and each was made from coaxial cable. Two of these leads were supported by straps on the front of the harness and could be used in either the sternal or axillary lead configuration. The third lead travelled around to the back of the subject where it served as a common lead.

Laboratory checkout equipment. - This equipment, as shown in Figure 7, served to detect any anomalies in the attached bioinstrumentation before the subject proceeded to don a flight suit or full pressure suit. The ECG signal could be viewed on a dual trace oscilloscope or an ECG recorder. The recorder provided the additional convenience of permanent records when desired. A specially fabricated balance box and D.C. amplifier combination was used to check the temperature sensing circuits and the subject cable. Figure 8 shows the subject cable connected to the console for checking the bioinstrumentation harness prior to connecting the subject cable to the electrical box on the instrument pack.

Instrument pack. - A back pack served as a mounting platform for certain instrumentation, physiological equipment, and environmental control system components. Instrument Pack I is illustrated in Figures 9 and 10 while Figures 11, 12, and 13 provide an illustration of Instrument Pack II. These photographs show the electrical junction box, cables, sensors, intercom preamplifier, respiration detector, and respirometer. Since many of the same variables were monitored using different instrument packs (described in Part I of this report under ECS System), the components of the instrumentation system were readily transferred from one instrument pack to another. The vibration sensitive components in the instrumentation system were oriented so that they were unaffected by jarring through the longitudinal axis of the instrument packs.

Electrical junction box. - A top view of the electrical junction box with other components of the system is presented in Figure 14. The differential physiological preamplifier can be noted near the upper edge of the electrical box. In the right hand portion of the junction box is seen the rotary solenoid switch, used to multiplex the various temperature sensors. Various connectors and the two switches to control the ECG preamplifier and respiration rate detector power may be seen on the front of the box. The bioinstrumentation harness is to the right with various sensors shown below the box. Not shown are the transducers which sense the temperature of the expired breathing gas at the discharge port in the respirometer and the pressurization flow. The umbilical and sensor connectors are of the quick disconnect type which expedite cable detachment.

Umbilical. - Figures 15 and 16 have been included to demonstrate features of the 200-foot (6096cm) umbilical cable. The electrical cables were laced together with the full pressure suit pressurization line and placed on hangers spaced at even intervals, which

were in turn suspended from a single guy wire behind the walkway. Thirty feet (914.4cm) of the umbilical at the subject end was covered with clear plastic tubing which had been stained black inside. The tubing prevented chafing of the electrical cables and pressurization line and de-emphasized the light colored cables for biomechanical data photography. Immediately prior to the start of the plastic tube, the communication cable for the escort's mike-headset unit emerged. At the subject end of the tubing, the subject's intercom cable was separated from the main instrumentation cable and connected to the subject's intercom preamplifier located on the back pack. The end of the umbilical cable away from the subject terminated in the control console in the test control center. All of the individual cables which comprised the umbilical were shielded and had a weatherproof plastic outer covering for protection.

Test control station. - The console in the test control center contained equipment which was part of the instrumentation and environmental control systems. The instrumentation power supply is noted beneath the writing shelf shown in Figure 25. Above that is the intercom master control unit which is installed below the various power switches, remote control switches and indicators, and the digital counter used to indicate the temperature point. The temperature indicator is the lowest of the three instruments on the upper left side of the console. The upper instrument shown is the respiratory rate meter and beneath that is the cardiac rate meter. The panel at the very top contains an electric clock and intercom speaker. The back of the control console contained the system patch panel where the umbilical cable terminated and where filters, attenuators, etc., were placed.

Adjacent to the control console is an eight channel biomedical strip chart recorder, used to record both real time events and the information played back from magnetic tape recordings. The speaker and amplifier partially in view on top of the paper recorder were used for listening to the voice track on playback. The preamplifiers noted in the recorder were selected for optimum signal handling based on their characteristics.

The magnetic tape recorder is seen to the right in Figure 17. In the background is a storage test oscilloscope for monitoring and instrumentation trouble shooting. The tape recorder handled four channels of information as shown earlier in Figure 2. Also noted in Figure 2 are the real time events recorded on the biomedical recorder (the first five listed) and the reproduced information from the magnetic tape recorder (the last three items).

General Instrumentation

Respiratory rate detector. - The first type respiratory rate detector used employing a piston, is shown in Figures 18 and 19. These pictures reveal the microswitch that activated the circuit electronics and the mounting method used on instrument pack 1. The second type detector, utilizing a thermistor, is shown in Figures 20 and 21 where it can be noted that the sensor was mounted in the respiratory valve. Both detectors were in the expiratory hose that entered the respirometer.

Full pressure suit pressure, temperature. - As can be seen in Figure 11, the full pressure suit pressure transducer was mounted in the pressure tank containing the respirometer. This transducer was a strain gage type receiving its excitation from a carrier preamplifier in the biomedical recorder. The tank was pressurized by the flow from the pressure suit outlet hose. Not seen in this figure are the two thermistors

used to sense ventilating air temperature, one in the inlet hose to the suit and the other at the discharge end of the outlet hose.

Globe thermometer. - The globe thermometer was designed and built at NSL, excluding the purchased copper sphere. Three views of this instrument are shown in Figures 22 through 24. The temperature sensing thermistor was a standard thermal sensitive resistance device, as were all of the thermistors in the system. The bottom portion of the thermometer was built out of a modified flashlight case. The small motor used to drive the mixing fan was a commercially available type meant to be energized by solar cells. The motor, shown in Figure 23, is attached to a base which formed part of the switch used to activate the motor. The wood dowel below the base takes up the space normally occupied by a flashlight battery, since the motor only required one cell for sufficient power. The pictures presented indicate its various components and how it was normally used. A bus line below the walkway (Figure 24) ran from the console in the test control center to two junction boxes. This arrangement made it easier to change locations for the globe thermometer.

Communications network. - The communications network block diagram was given earlier in Figure 2. The system hardware is shown in Figure 25. The mike-headset units, preamplifiers, and main amplifier were of the AIC type which made the system compatible with government AIC/10 equipment. Since the subject, escort, and biomechanics data photographer were a considerable distance from the test control center, and the microphones were the low impedance type, each of the three stations had a small preamplifier to boost the microphone output. The preamplifiers were built into a small case that also contained a mike switch and headset volume control. The preamplifiers were powered by energy from the system power supply which was fed out to the individual stations over the intercom cables. The mike-headset units used in the test control center did not have preamplifiers, but each did have the control box with volume control and mike switch. Additional volume controls are shown on the front of the main amplifier, including one which controlled the speaker output level.

RESULTS

System Operation

The system was developed and fabricated so that the Test Director could run a test program and record information from one position while seated in front of the operating console in the test control center. The visual display consisted of heart rate in beats per minute, respiration rate in breaths per minute, and any one of the fourteen temperature points selected (in degrees Fahrenheit). This information, readily visible, was used as an indicator of a subject's metabolic level at a particular instant. The matrix shown in Figure 26 indicates the relationships of the test control station operations.

Operation of the biomedical recorder could be initiated or stopped by remote control from the operating console, as could the magnetic tape recorder. Indicators adjacent to these controls revealed the various modes of instrument operation. The temperature points, either physiological or environmental, were selected by depressing a small button on the console shelf which activated the multiplexing motor in the electrical box. A reference point in the electrical box allowed synchronization between the digital

counter on the front panel and the temperature point being monitored. The various temperatures were logged onto data sheets by hand as they were being scanned.

Since the biomedical recorder was near the operating console, the Test Director could make notes on the chart paper prior to each run. The real time events such as temperatures, full pressure suit pressure, respiration rate, and cardiac rate utilized the left four channels of the eight channel paper with the one second timing mark on the right hand margin (see Figure 27).

Magnetic Tape Playback

The magnetic tape recorder was integrated into the system so that as the real time information was recorded on the magnetic tape, the reproduced information was recorded on the right three channels on the biomedical recorder chart paper. This information consisted of the respiration rate, cardiac rate, and time pulses.

If, at a later date, reference to the stored data was desired, the tape was replayed and the information reproduced on the chart paper. At that time, the voice transcription identifying the test profile was available. One of the advantages of using magnetic tape to store information was the conditioning or signal enhancing possible on playback. The use of a magnetic tape recorder was a rather redundant provision since the information needed from a test run was available on the chart paper, but it did provide a recapitulation of test runs if desired.

DISCUSSION

Temperatures

Before proceeding to design the temperature sensing and readout system, preliminary figures were calculated to obtain the system error due to the umbilical cable. A graph of the resistance of thermistors to be used as a function of temperature (1) is included in Appendix A of this part. Based on the possible use in the umbilical cable of number 18 (AWG) annealed copper wire, resistance per thousand feet for three different temperatures were calculated and found to be 5.9, 6.4 and 7.0 ohms at 30 °F, 70 °F and 110 °F respectively (2). Assuming the worst case condition where the umbilical would reach a temperature of 110 °F, and the Δ R's for the thermistors were based on the most used ranges of 75 °F to 95 °F and 90 °F to 110 °F, the worst system error was less than 0.2 °F in the last mentioned temperature range. These figures were corroborated by correspondence between Northrop Corporation and the instrument manufacturer (3).

The interchangeability tolerance for the thermistors used has a maximum deviation of 0.36 °F at 30 °F and drops to 0.18 °F at 110 °F. A nominal value of 0.27 °F interchangeability tolerance exists at a thermistor temperature of 70 °F (1). However, this tolerance is probably included in the manufacturer's accuracy specification of ±0.25 °F over the entire range of the instrument (1). It would appear, then, that the worst system error would be less than ±0.5 °F at an umbilical temperature of 110 °F and in the operating range of 95 °F to 110 °F. In view of this error, calibration tests were

run with the umbilical (at 75°F) in the system. The results were presented in Appendix A of this part and indicate that the deviation appears to be more a function of the calibrating thermistor than the umbilical resistance, at this temperature. (Note the mercury bulb thermometer readings.) During the fabrication of the system, one thermistor gave an extreme reading, and when replaced, the temperature readings were within the tolerance limit.

Another facet considered in designing the system was the choice between fourteen cables in the umbilical for each thermistor, the use of one cable and a multiplexing rotary switch, or the use of one cable and multiplexing reed switches. The first suggestion was ruled out because of the bulk and weight of the many cables that would be present in the umbilical. Reed switches were investigated, but over a period of use their contact resistances would increase, and they are fragile. A rotary solenoid driven switch was chosen because the use of wiper contacts resulted in a contact resistance of less than 10 milliohms over a prolonged period of use.

The surface temperature probes used had the thermistor grounded to one side of the metal outer case. To protect the subject from ground loops between the probe cases and the common heart rate electrode, the cases were potted with a thin layer of Silastic rubber. This thermal insulation could have introduced a small amount of error into the temperature readings, but electrical isolation was preferable to the small temperature error.

The globe thermometer was designed to use an air temperature type probe. The sensing element of this probe was located in the center of the sphere. Thermal insulation was provided between the metal of the probe and the sphere by means of a nylon bushing, which also provided electrical insolation. Information describing this instrument in References 4, 5, and 6 indicated a six-inch (15.24cm) sphere was optimal, hence this size was chosen.

The sphere was made by a spinning company which made two hemispheres then joined these together by cold soldering. This method of joining avoided warpage of the sphere which would have occurred had silver soldering been used, since the walls were thin. The walls were made of twenty-thousandths inch (.0508cm) thick copper sheeting which was reduced to fifteen thousandths by spinning. A two-inch (5.08cm) hole was cut in the bottom of one of the hemispheres prior to joining with its mating part, which provided access for the fan and flashlight case. The top of the flashlight was threaded and screwed into a threaded bushing which had been cold soldered to the sphere.

The cabling to the two junction boxes which received the connector from the globe thermometer was a maximum length of fifty feet (1524cm). This cable consisted of two 18-gage wires inside a shield and in view of the previous discussion about the umbilical cable, contributed little error to the temperature readings. The time necessary for the instrument to stabilize was determined in a still environment, and found to be sixteen minutes. Since the location where the globe thermometer was used was windy, the temperature readings deviated in a range of four degrees, as shown in Appendix A. A mercury bulb thermometer exhibited a similar variation, although in a narrower range.

Heart Rate

When physiological testing began in the first phase of this contract, various methods of recording ECG on the subject walking on a treadmill were investigated. The first

attempt at recording heart rate under these conditions was by use of a three electrode bipolar lead system (7). The first of two configurations used consisted of one lead to the manubrosternal junction, the second lead to the lumbrosacral junction, and the common lead was applied at T8. The second arrangement consisted of the two electrodes being attached over the right and left midaxillary lines and the common lead placed over the lumbrosacral junction (7). Depending on the subject, one or the other systems resulted in acceptable records when the ECG signal was conditioned by means of cut-off filters in the recorder.

After this, testing was conducted while the subject was performing on the lunar gravity simulator. This position was one in which the subject was supported on his right side while nearly horizontal. Although many investigators have studied the problems of obtaining acceptable ECG recordings from active subjects (8, 9, 10, 11, and 12), this arrangement introduced new problems not heretofore studied. The axillary placement of electrodes that had previously resulted in good ECG information resulted in considerable noise generation and discomfort to the subject. These problems were due to varying amounts of pressure on the right electrode nipple which was on the supporting side of the subject. This variation in pressure caused a continuing change in the electrode-skin junction impedance and also a pressure point on the subject's right side. Changing to the sternal configuration did not always alleviate the problem; therefore, some new techniques were tried.

Since the axillary or sternal position lead configurations have been generally accepted for monitoring of active subjects in aerospace environments (13), improvements to these methods were undertaken. Concurrent with the procuring of several modified NASA Manned Spacecraft Center (MSC) Mercury ECG flight electrodes, the ECG leads in the bioinstrumentation harness were changed to special coaxial cable (10). The introduction of these materials diminished the noise in the recordings considerably and increased subject comfort. A later change was made to the use of newer type ECG electrodes which resulted in improved results and these were used for the remainder of the program.

Additional improvements to the system included extensive filtering. Since the physiological determinations were based on heart rate, and not the clinical evaluation of the ECG, no attempt was made to preserve the PQRST complex, other than the R portion. The filtering used was purely R-C and was designed to pass a limited range of frequencies (1 to 20 cps) considered to include most of the desired information (13). When the recording on the biomedical recorder became illegible due to extensive subject movement, the filtering into the magnetic tape recorder removed additional myogram and artifact. Subsequent playback of the magnetic tape and the recording on the biomedical chart paper recorder at high chart paper speeds made it possible to determine the cardiac rate.

Subject protection was afforded by the use of a solid state differential preamplifier in the electrical box. Shielding from the input to the biomedical recorder preamplifier was carried through the complete system, with the physiological preamplifier case serving as a continuation of the cable shield. The preamplifier case was isolated from the grounded electrical box. The shielding on the subject end of the heart rate leads was left floating, terminating six inches from the actual electrodes. Additional shock protection was by means of a 2 milliampere patient fuse in the common electrode return to the biomedical recorder preamplifier.

System checkout was possible by use of a small pulse generator (lower right corner of Figure 14). This instrument was a one transistor device that had the same type connector as the distal end of the subject cable. When problems arose in the recording of

the heart rate, it was possible to determine what portion of the system was at fault by merely plugging the generator into the electrical box. This activated the unit which oscillated at 156 beats per minute resulting in a differential output signal of one and a half millivolts. The unit was built on a small phenolic board which was attached to the connector, and all components including the battery were potted using Silastic rubber.

Respiration Rate

Several different methods of recording respiration rate were studied prior to the system design and the decision was made to use the expiratory portion of the subject's respiratory cycle to activate a micro switch. Since gas samples were collected from the respirometer, the sensor was located in the hose between the mouthpiece and respirometer. This technique of sensing the respiratory rate appeared preferable to other methods since it helped keep the subject instrumentation relatively simple. Alnutt (12) has shown several different methods of monitoring this physiological event and the limitations associated with each; therefore, the switching arrangement was chosen. Another decided advantage of using an activated microswitch was the generation of a rectangular pulse by the associated electronics, which when differentiated and half wave rectified, resulted in a very clean pulse received at the test control center.

The first respiration detector built consisted of a lightweight shutter in a cylindrical tube, which was moved by the subject's expired air. Movement of this shutter allowed light to pass through a small window on one side of the cylinder and fall on the face of an opposing photoconductor. A change in resistance of the photoconductor activated a relay in the electrical box, which in turn generated a rectangular pulse. The shutter was returned to its resting position by a hair spring, external to the sensor. The use of a cylinder for the body of the sensor resulted in a curved shape for the shutter, and since the shutter rotated about its upper edge, a small gap existed around its edges. Low breathing rates were insufficient to activate the shutter and adjusting the spring to increase the sensor's sensitivity resulted in the unit being susceptible to vibration and shock, and in addition, the lens through which the light passed frequently fogged up. Because of these problems, a different configuration was employed for a sensor but one still utilizing the expired air for activation.

The next unit was designed to use an "L" shaped tube through which the expired air passed and in so doing, activated a lightweight spring loaded piston. The small shaft which held the Formica disc in the center of the tube operated a microswitch on the outside of the sensor, as shown in Figure 18. The tube was chrome plated to resist internal corrosion caused by saliva. Resistance to movement of the plunger's shaft was minimized by using a teflon bushing. Space existing around the edge of the disc (piston) which decreased sensitivity was compensated for by the use of an "O" ring inside the tube which covered this gap when the piston was in a resting position. This helped overcome the piston's inertia on light breathing and break the bond between the piston and tube wall due to saliva. The operation of this unit was reliable at all breathing rates except the slowest so a more sensitive type pressure switch was investigated but found to have a limited range. Because of these problems, a change was made to a thermistor sensor which was used towards the end of the program.

Intercommunications Network

The intercommunications network was custom built for NSL by an outside vendor to fit the requirements of this contract. In view of possible expansion of this system and in an effort to be compatible with GFE equipment, all units were of the AIC type. This was of particular value when the subjects used full pressure suits furnished by the government.

The main amplifier had output provisions for an external speaker and a high impedance output for use with the magnetic tape recorder. The distances between the various stations necessitated voice preamplifiers at each of these stations. Since a choice between batteries or use of the system power to operate the preamplifiers was possible, the latter was chosen for reliability. Energizing of the main amplifier from the 25 volt DC system powered the preamplifiers at the subject, escort, and biomechanics data photographer. The system performed in a reliable manner, and the only times when the subject could not communicate was when using the respiration mouthpiece.

CONCLUSIONS

The instrumentation system described was reliable, economical, and resulted in obtaining the desired information. Knowledge obtained from use of this system indicates that it is feasible to use a hard wire umbilical over extended distances to obtain physiological data. Certain problems, particularly concerning temperature error, become pronounced and impose a limitation on umbilical length. Should heart rate only be of interest, it would appear feasible to look at other methods of monitoring to avoid myogram and artifact, particularly if a subject is performing at high activity levels. A consideration of primary importance is the avoidance of ground loops through the subject's body.

It appears that if the umbilical length were to be increased significantly the most serious limitation is imposed by the effects of temperature on system accuracies. This problem can be most effectively solved by the use of special circuitry which balances the temperature effects on the umbilical out of the bridge circuit.

The various methods tried to obtain respiration rate indicate that a thermistor sensor is preferable because of the back pressure created by electro-mechanical devices. In the various testing profiles encountered in this program, it became apparent that mechanical devices were susceptible to static and inertial forces and that a sensor sensitive enough to cover the complete respiratory rate range would also be affected by these forces.

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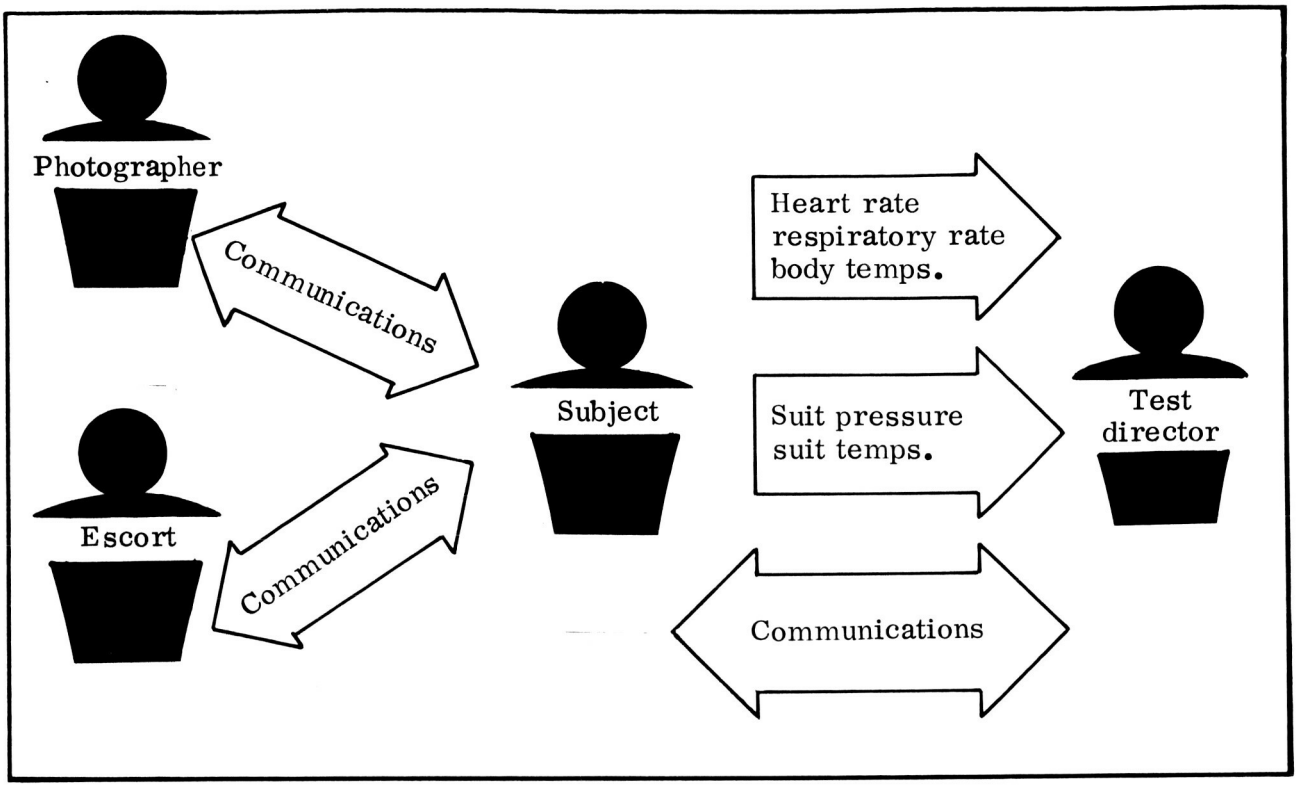

Figure 1. - Information flow diagram

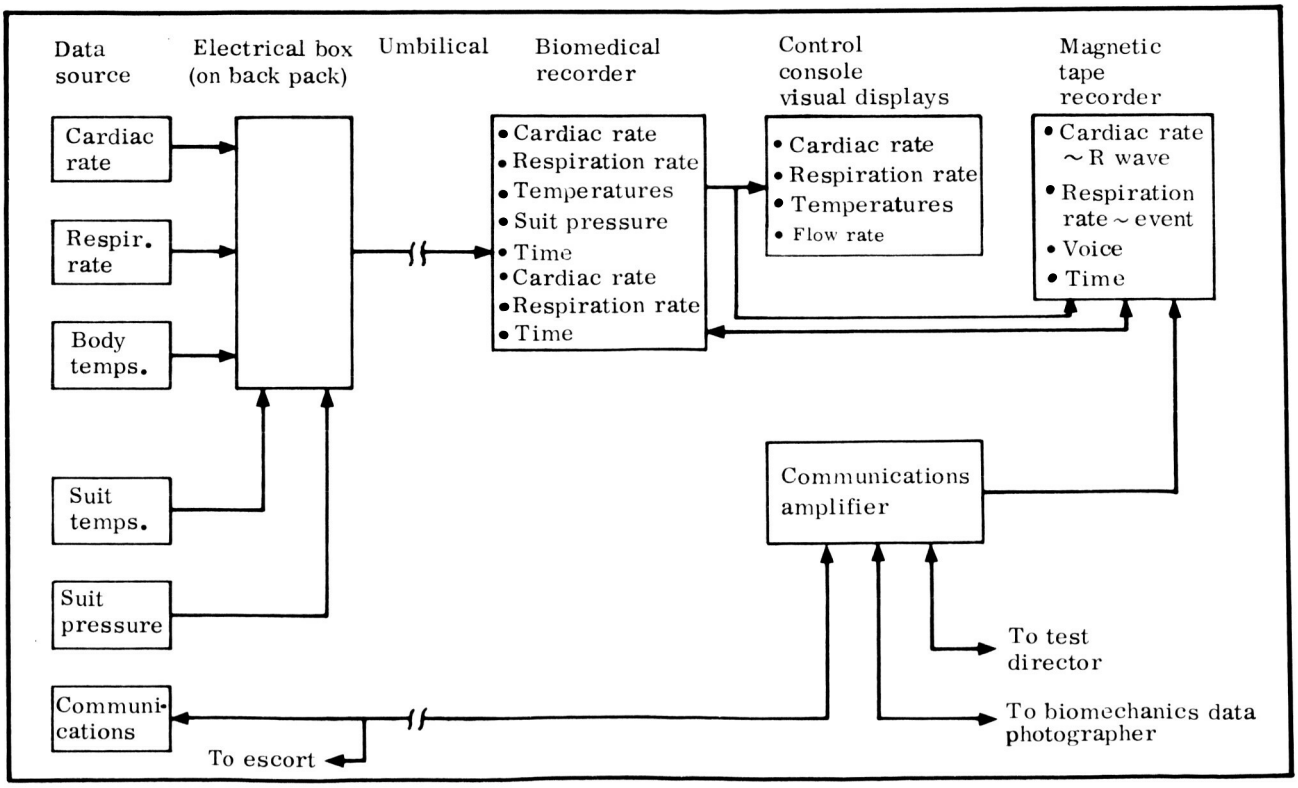

Figure 2. - System block diagram

Figure 3. - Front view, subject in harness

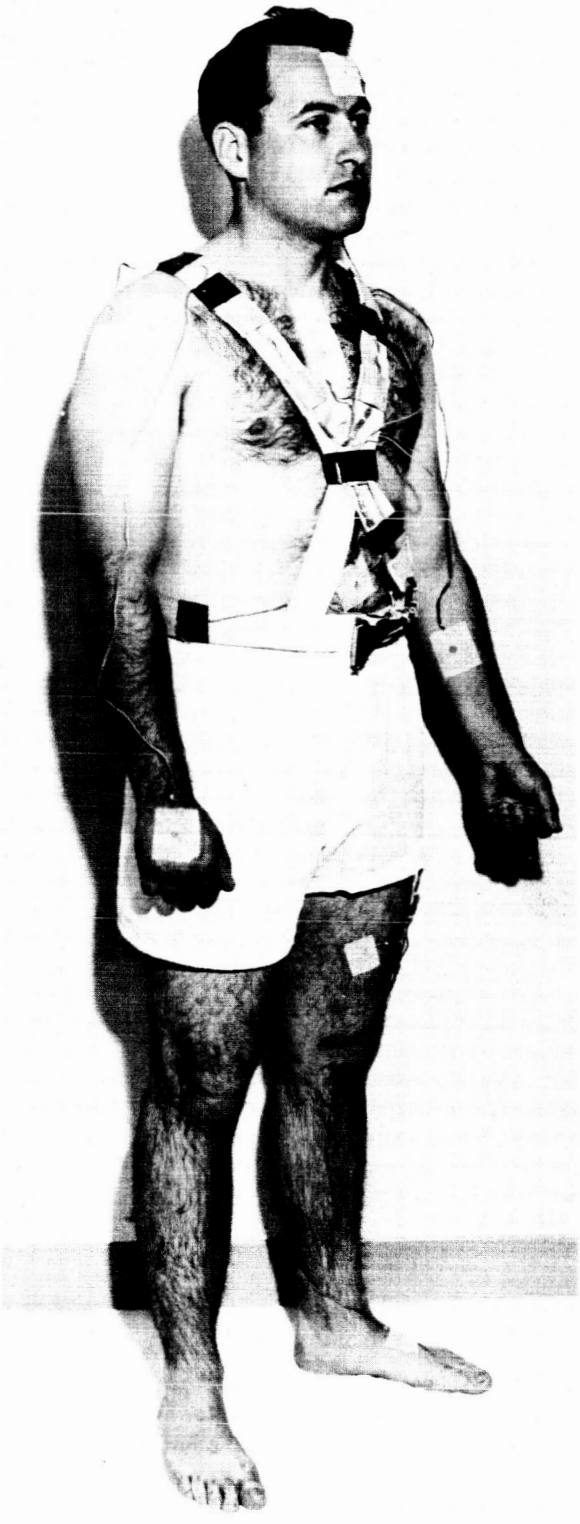

Figure 4. - Subject in harness, antero lateral view

Figure 5. - Subject in harness, posterior view

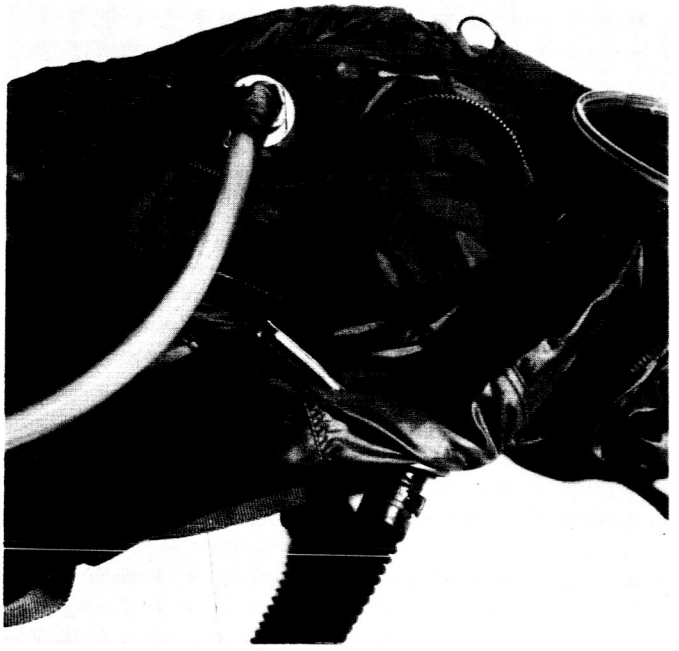

Figure 6. - Subject cable tnrough wall of full pressure suit

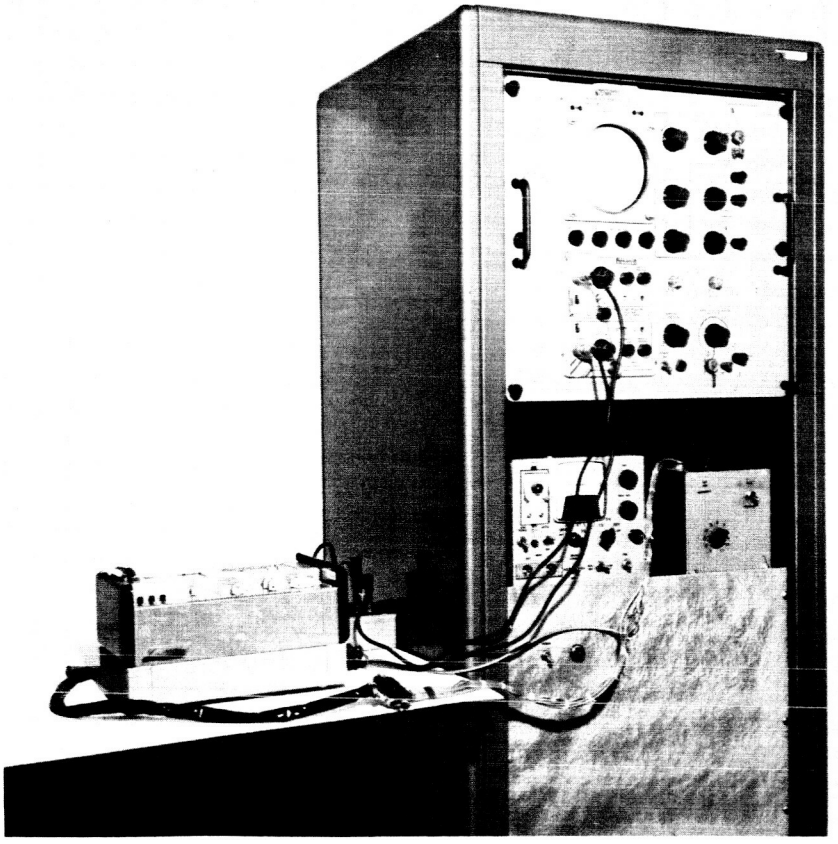

Figure 7. - Laboratory checkout equipment, console and ECG recorder

Figure 8. - Laboratory checkout equipment, pre-run

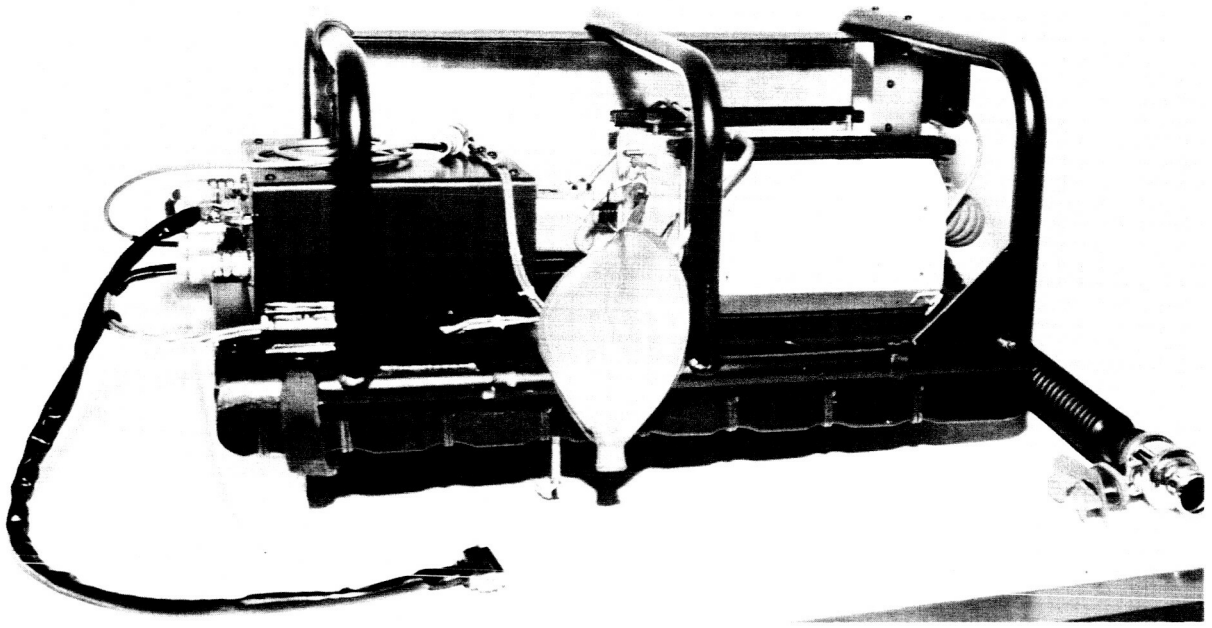

Figure 9. - Instrument Pack I showing respiration detector and electrical box

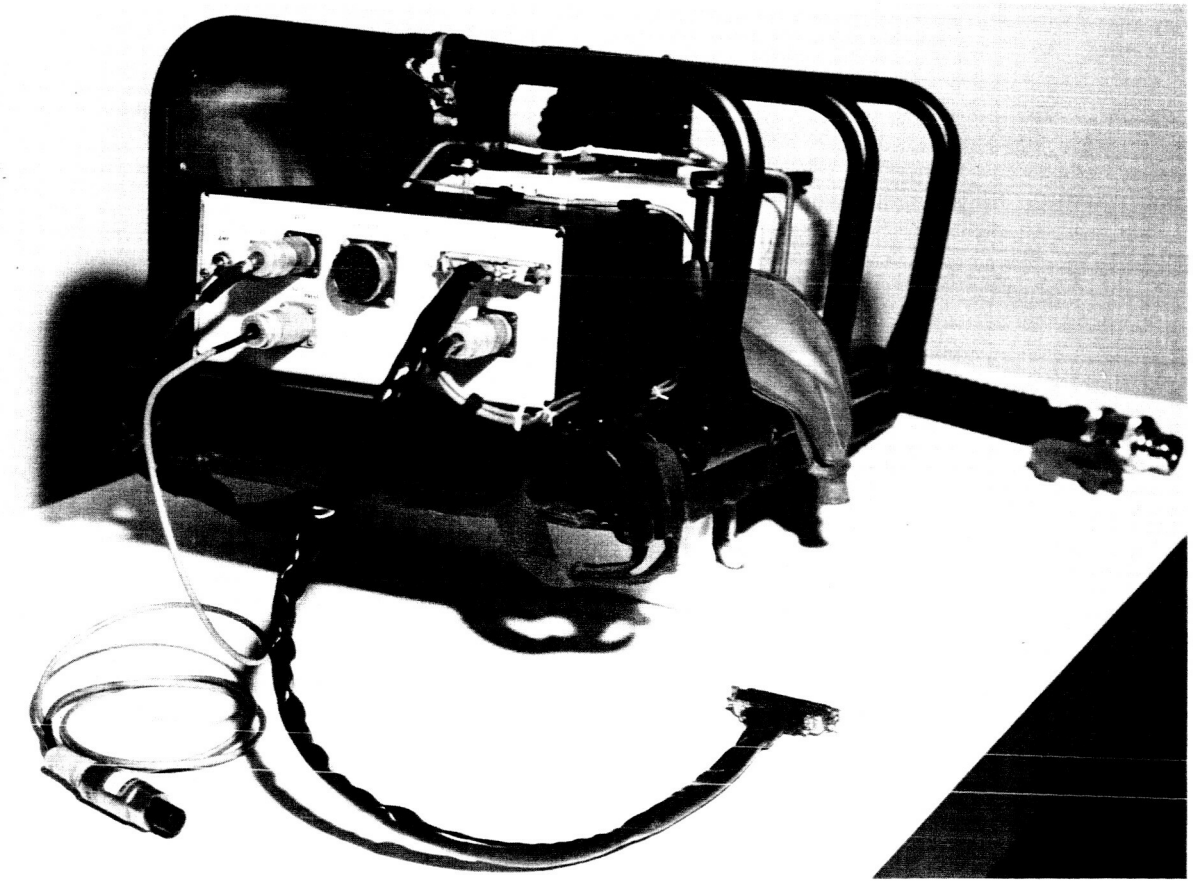

Figure 10. -Instrument Pack I showing electrical box connectors, sensors, and subject cable.

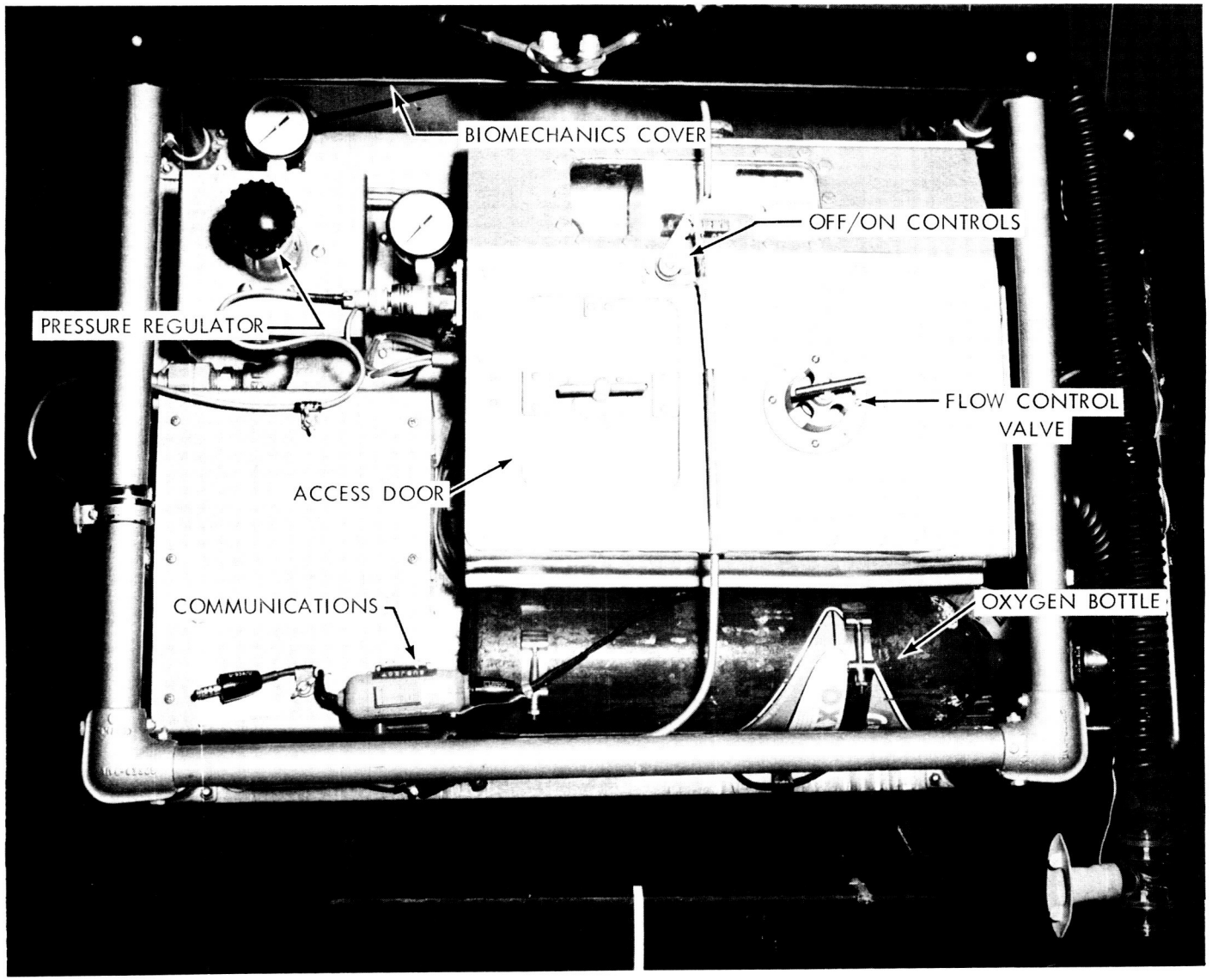

Figure 11. - Instrument Pack II showing electrical box and instrumentation, top view

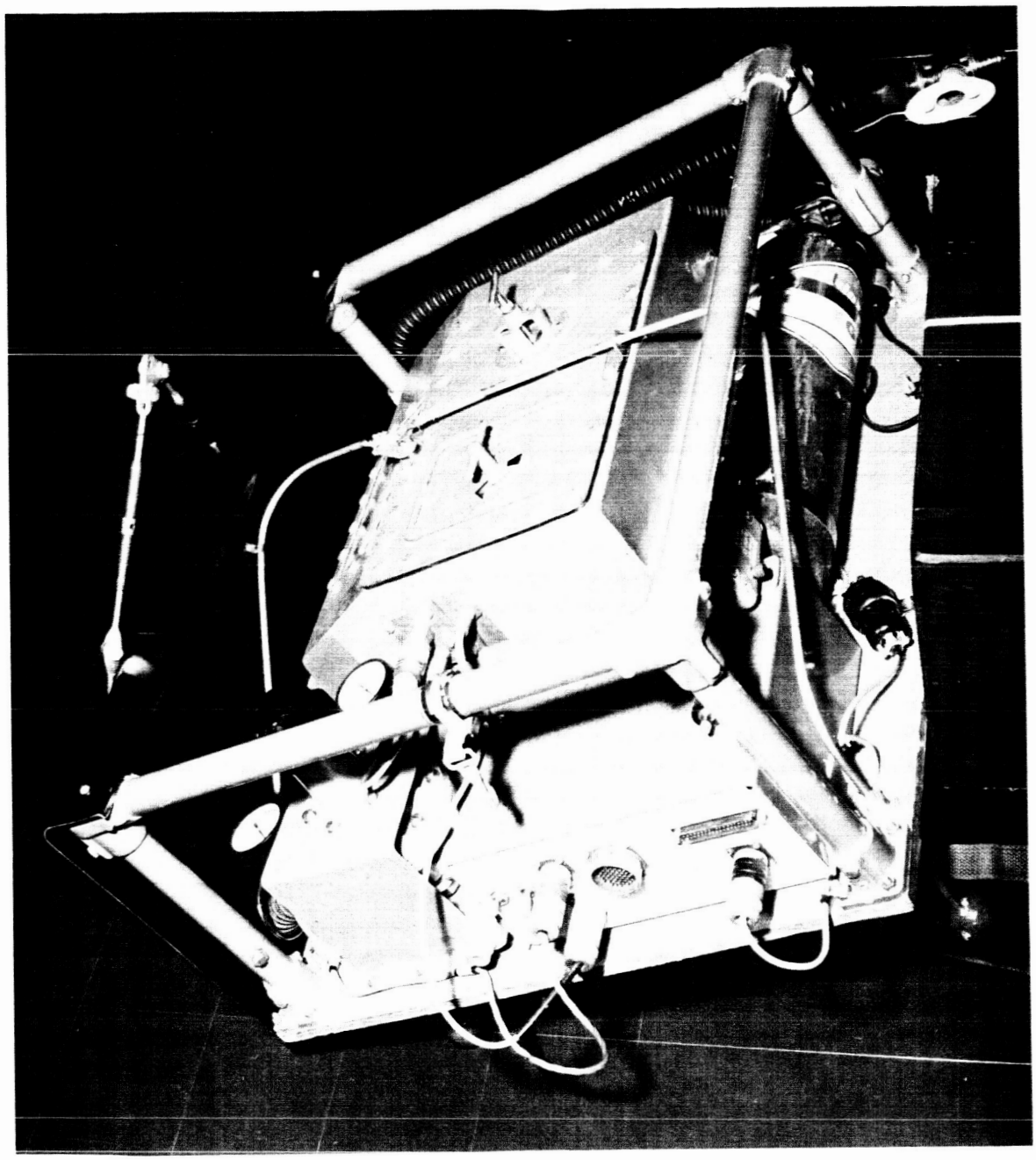

Figure 12. - Instrument Pack II showing electrical box and instrumentation, lower corner view

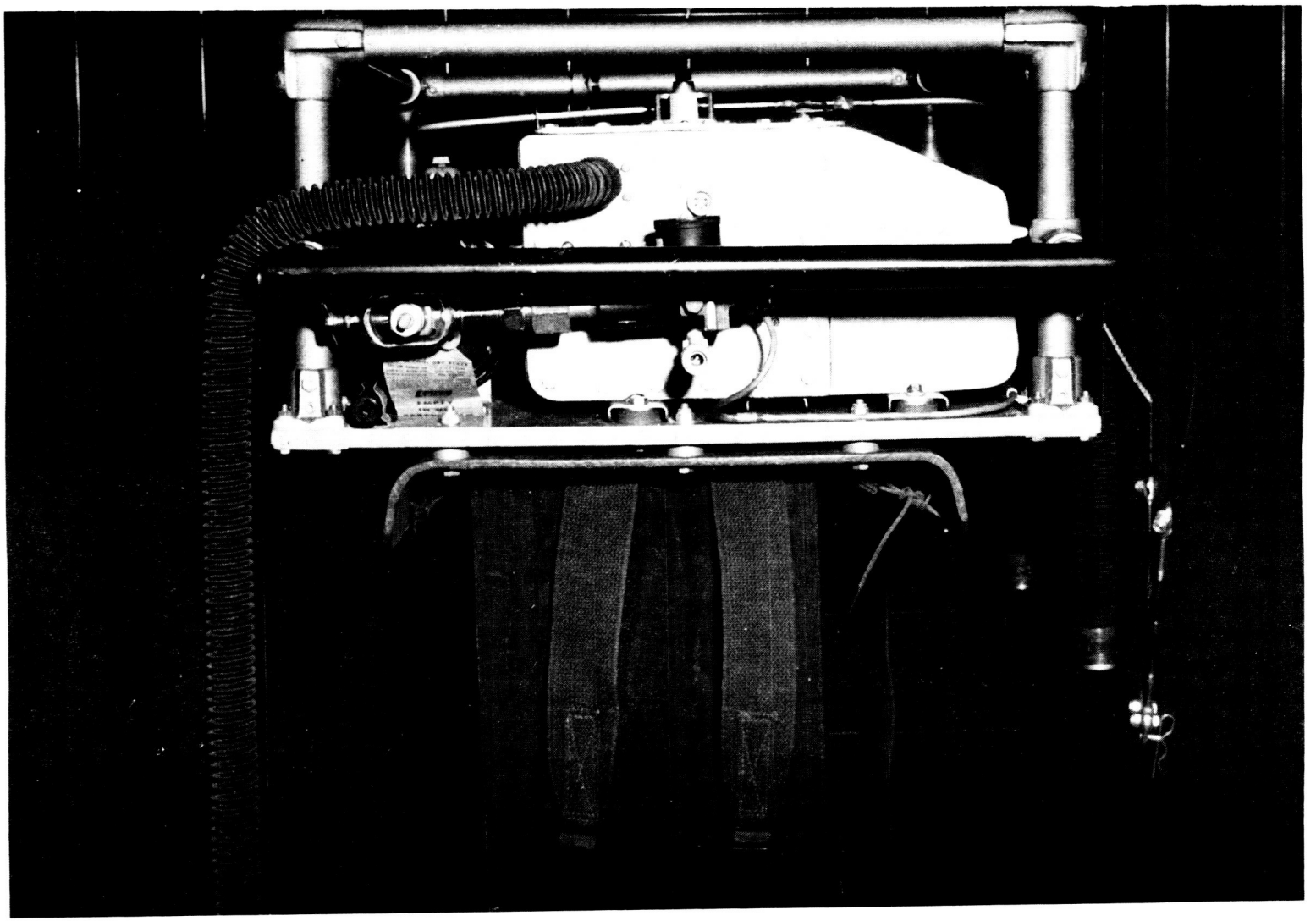

Figure 13. - Instrument Pack II showing respiratory hose connection and respiratory rate detector cover plate

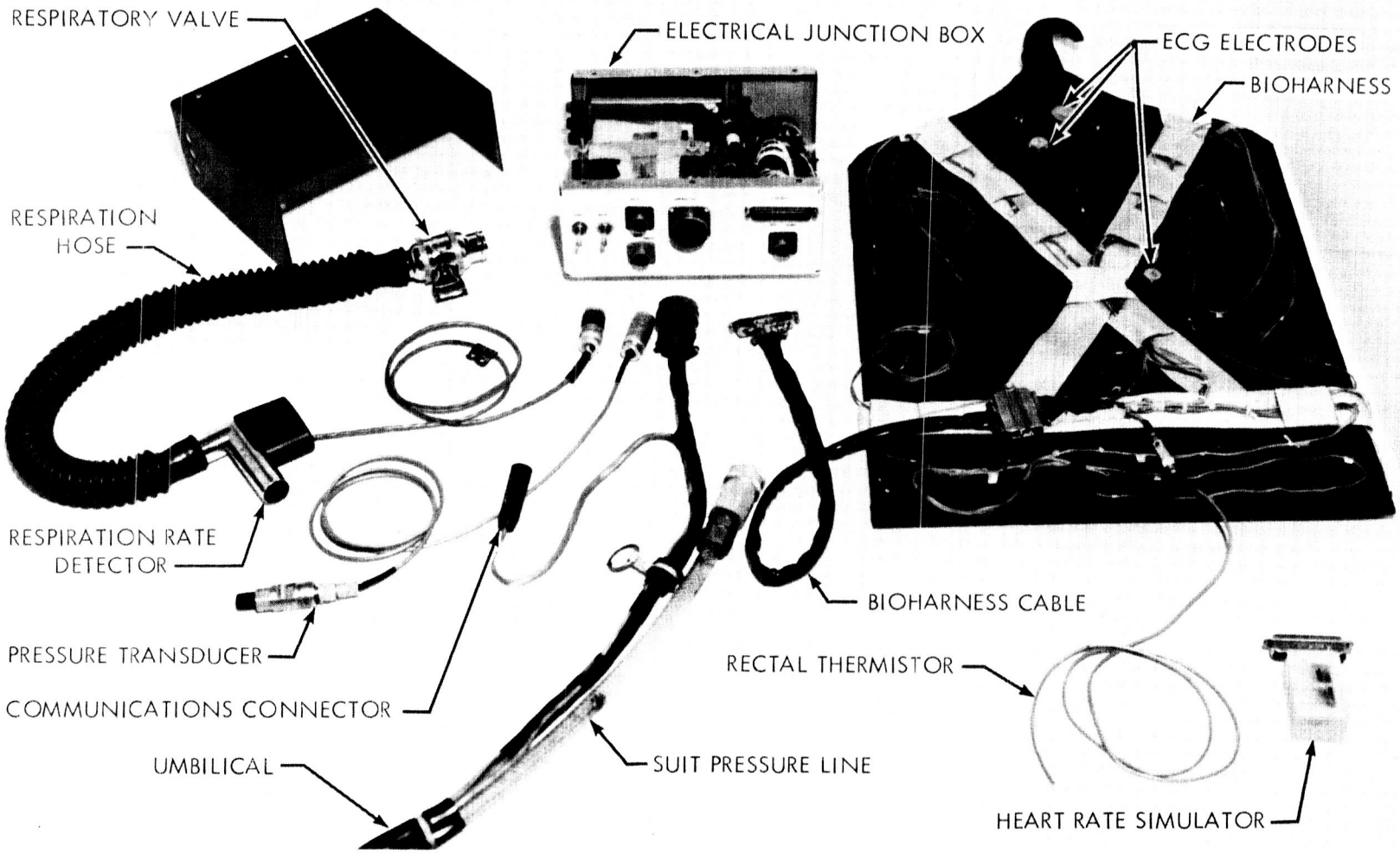

Figure 14. - Electrical junction box, associated sensors, bioinstrumentation harness, and umbilical

Figure 15. - Umbilical cable

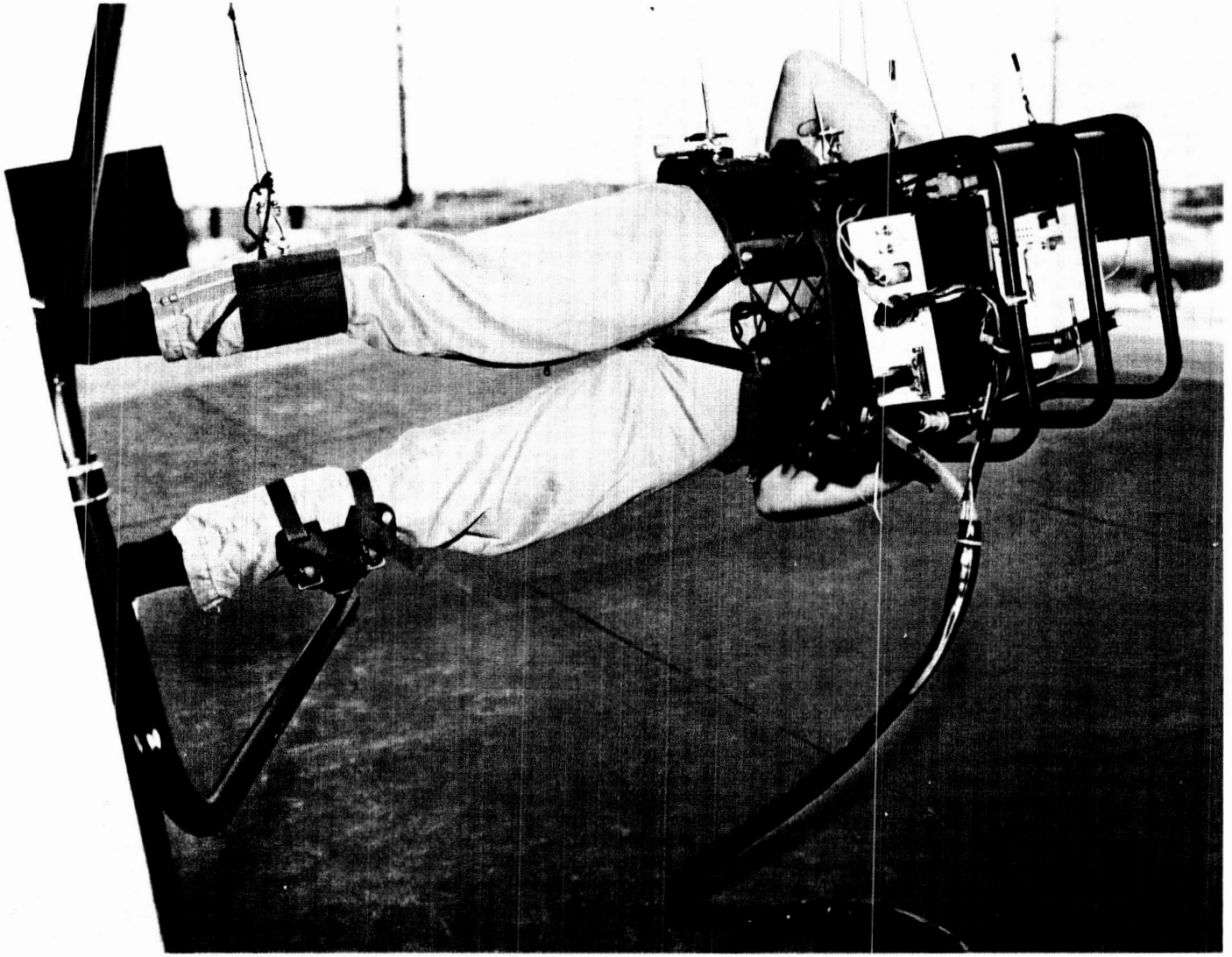

Figure 16. - Umbilical attached to electrical box on Instrument Pack I of subject on simulator

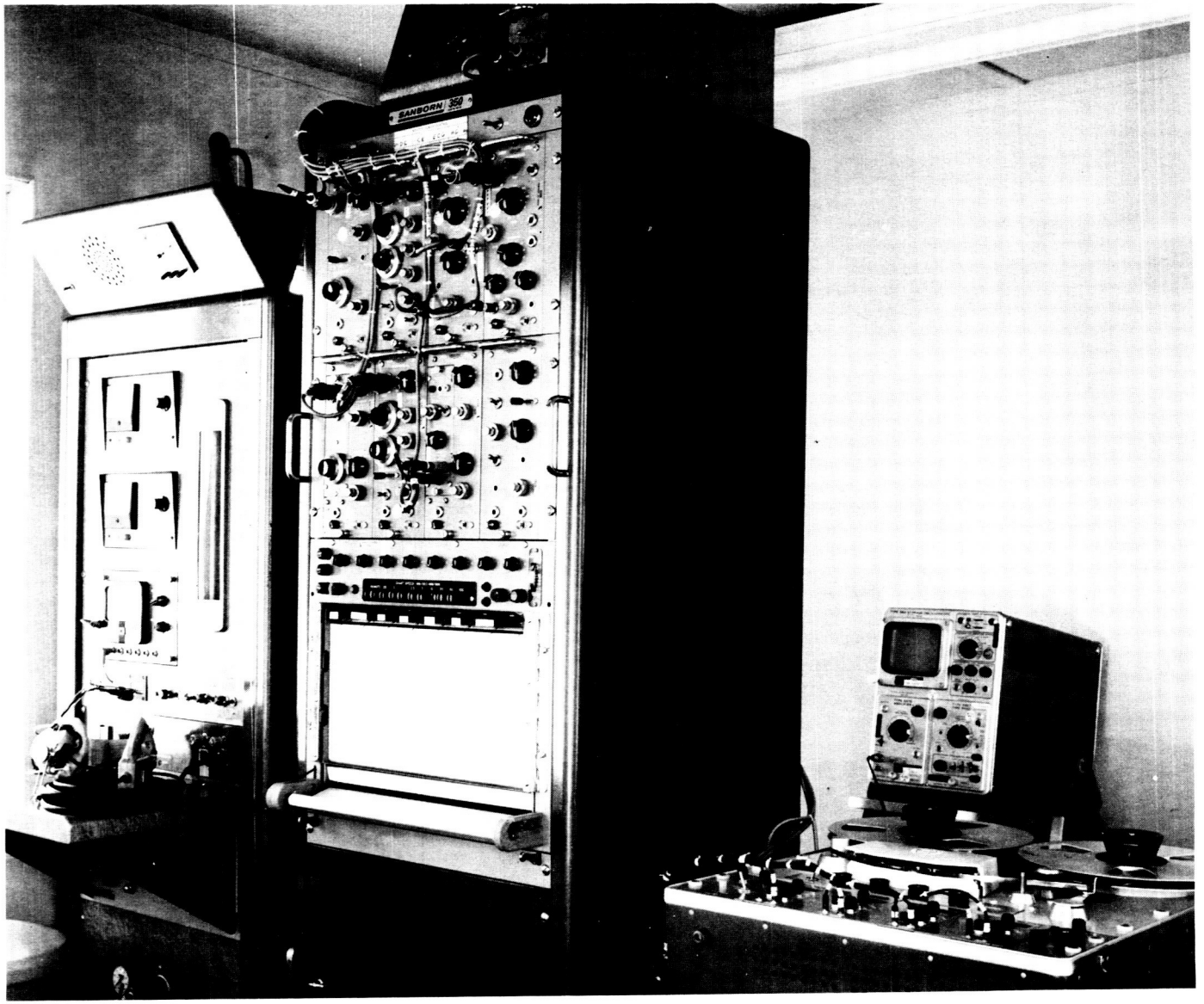

Figure 17. - Instrumentation and data recording equipment installation

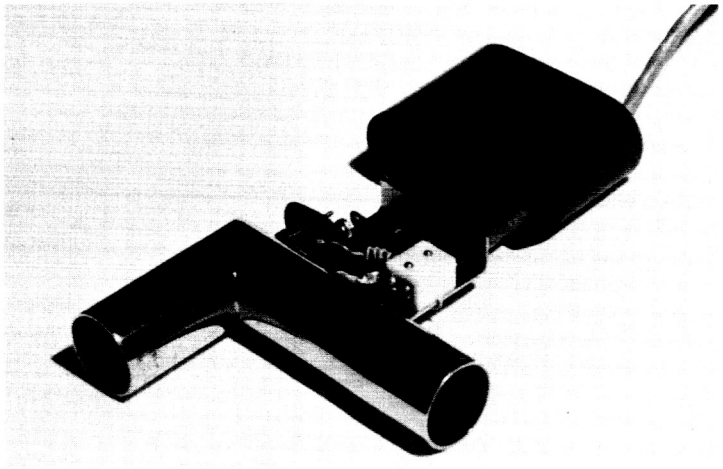

Figure 18. - Respiration rate detector, cover removed

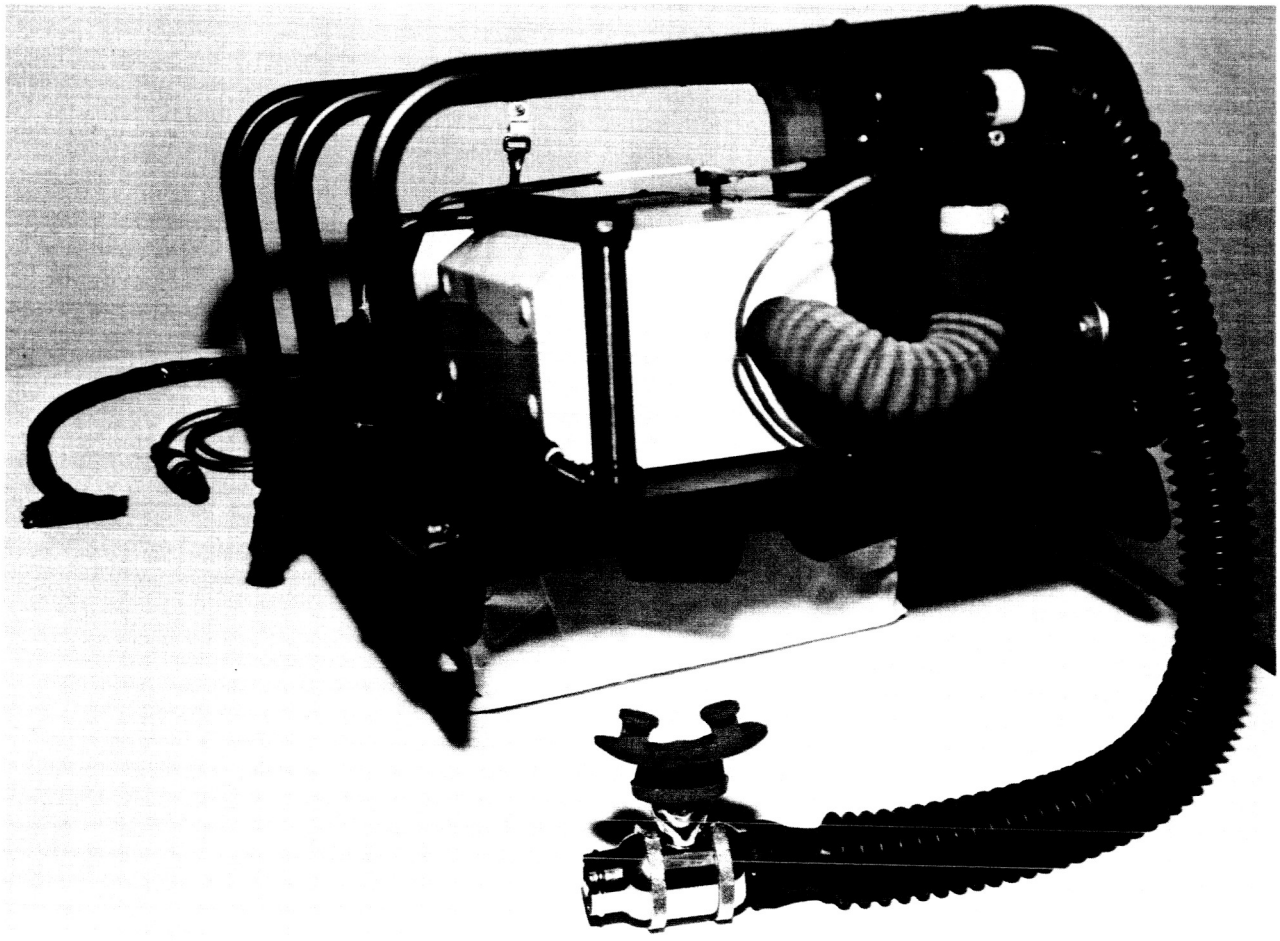

Figure 19. -Instrument Pack I showing respiration rate detector attachment

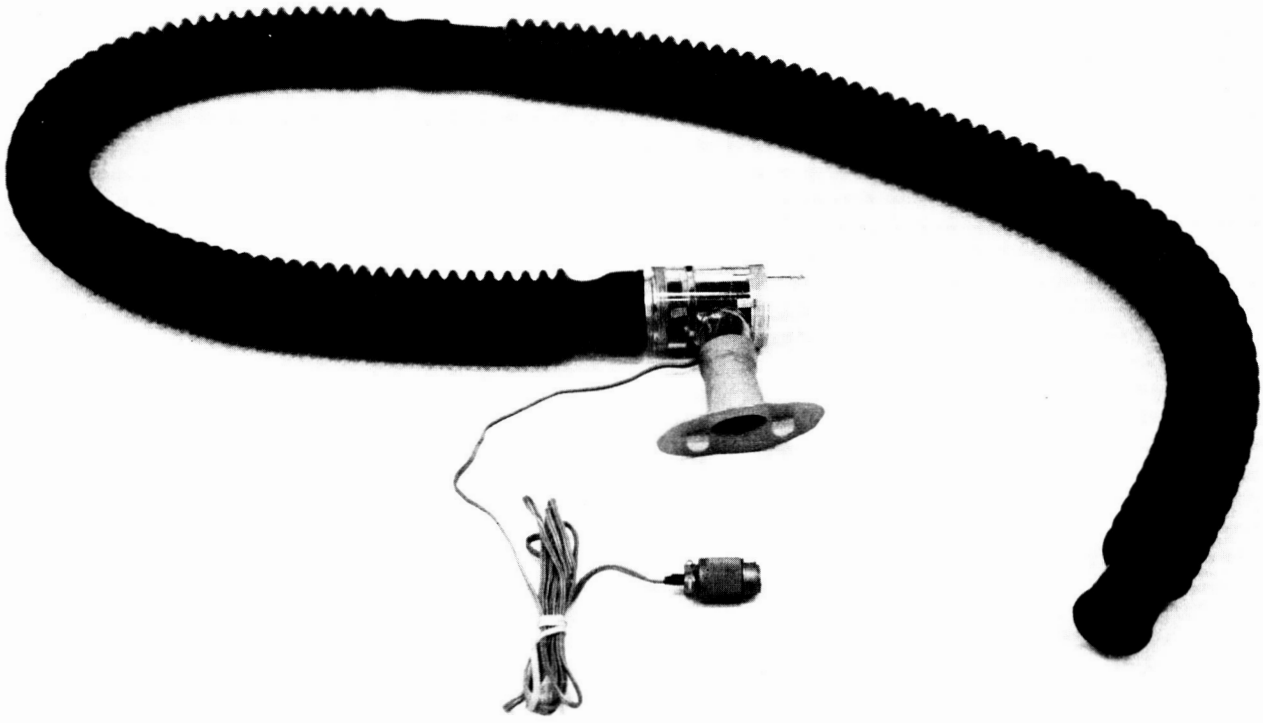

Figure 20. - Shirt sleeve suit respiratory valve with thermistor installation for respiratory rate detection

Figure 21. - Pressure suit helmet and respiratory valve assembly

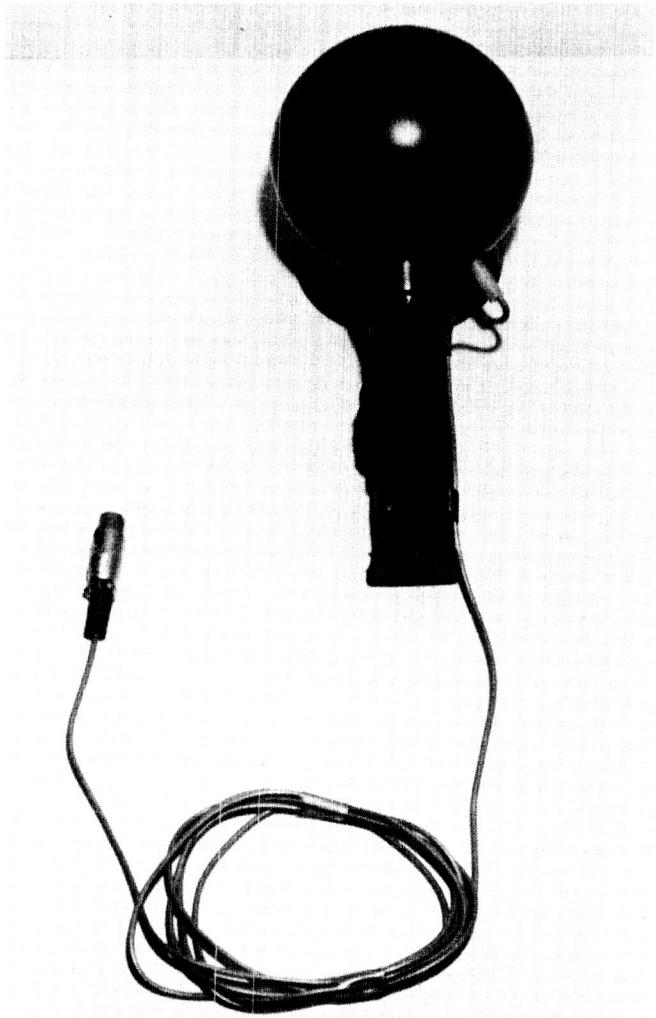

Figure 22. - Globe thermometer

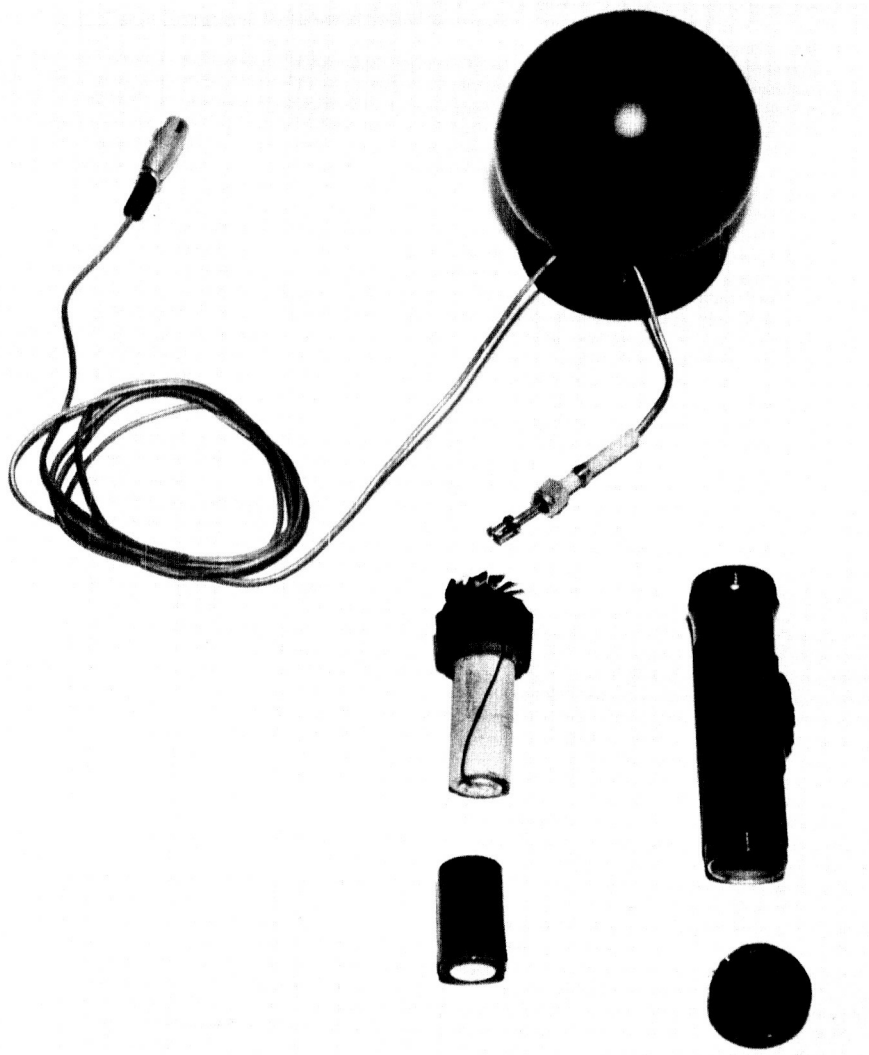

Figure 23. - Globe Thermometer, exploded view

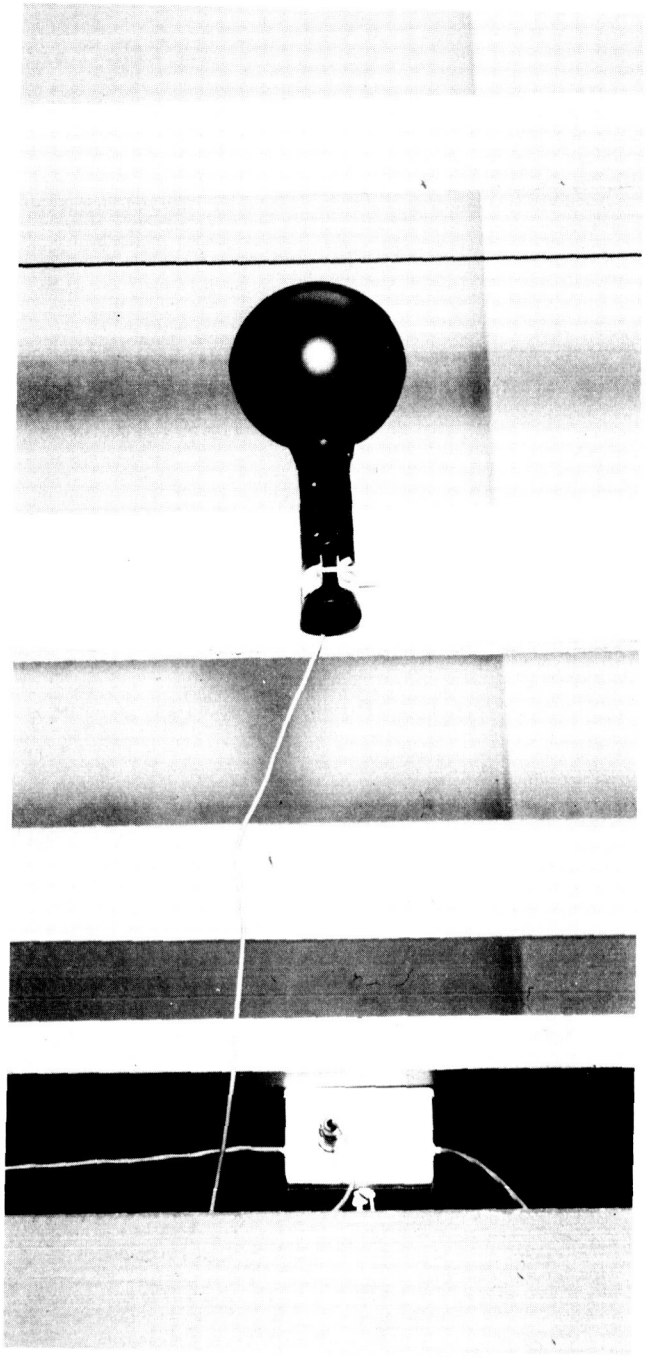

Figure 24. - Globe thermometer installation on catwalk over subject's test area

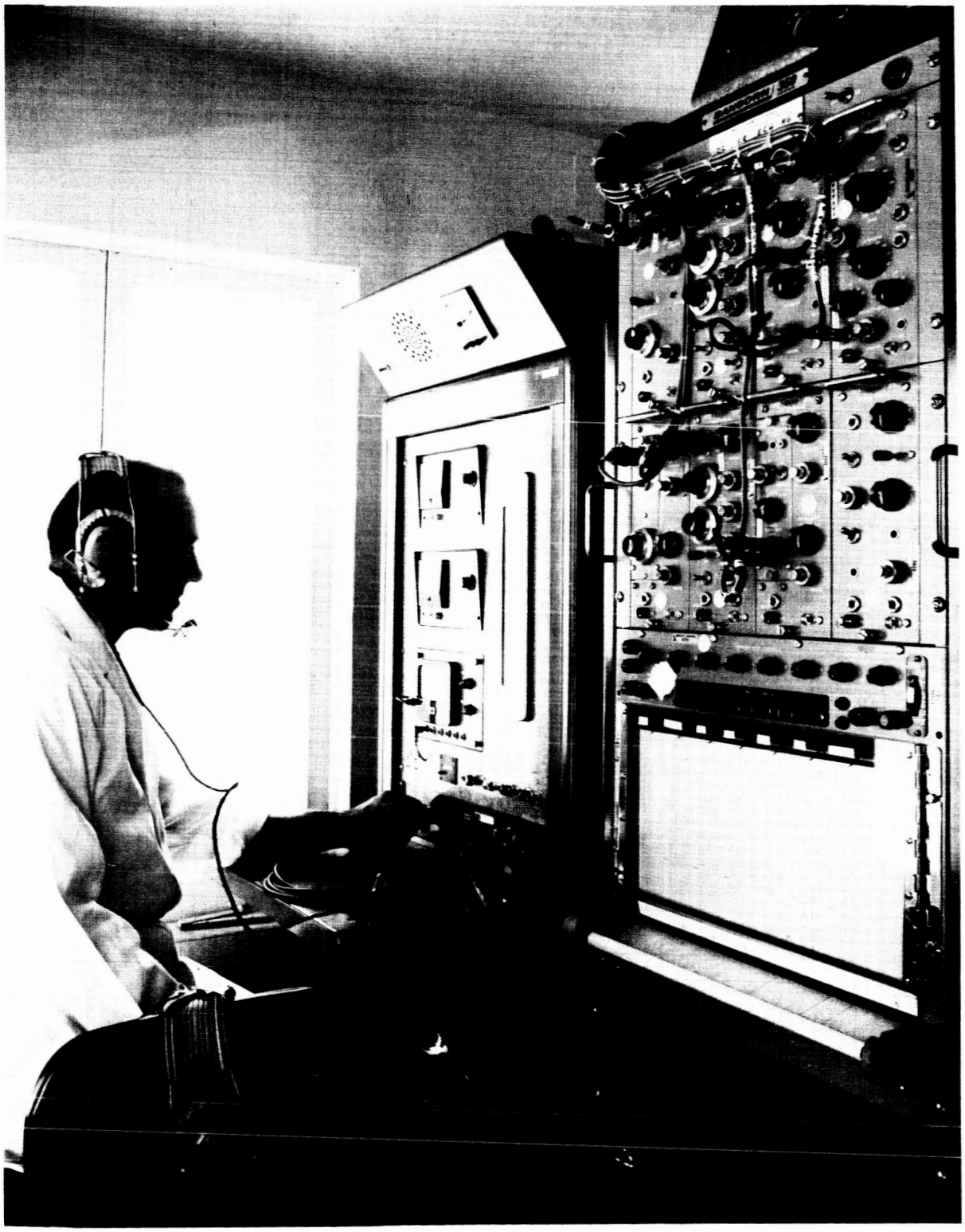

Figure 25. - Operator at test control station wearing mike-headset unit.

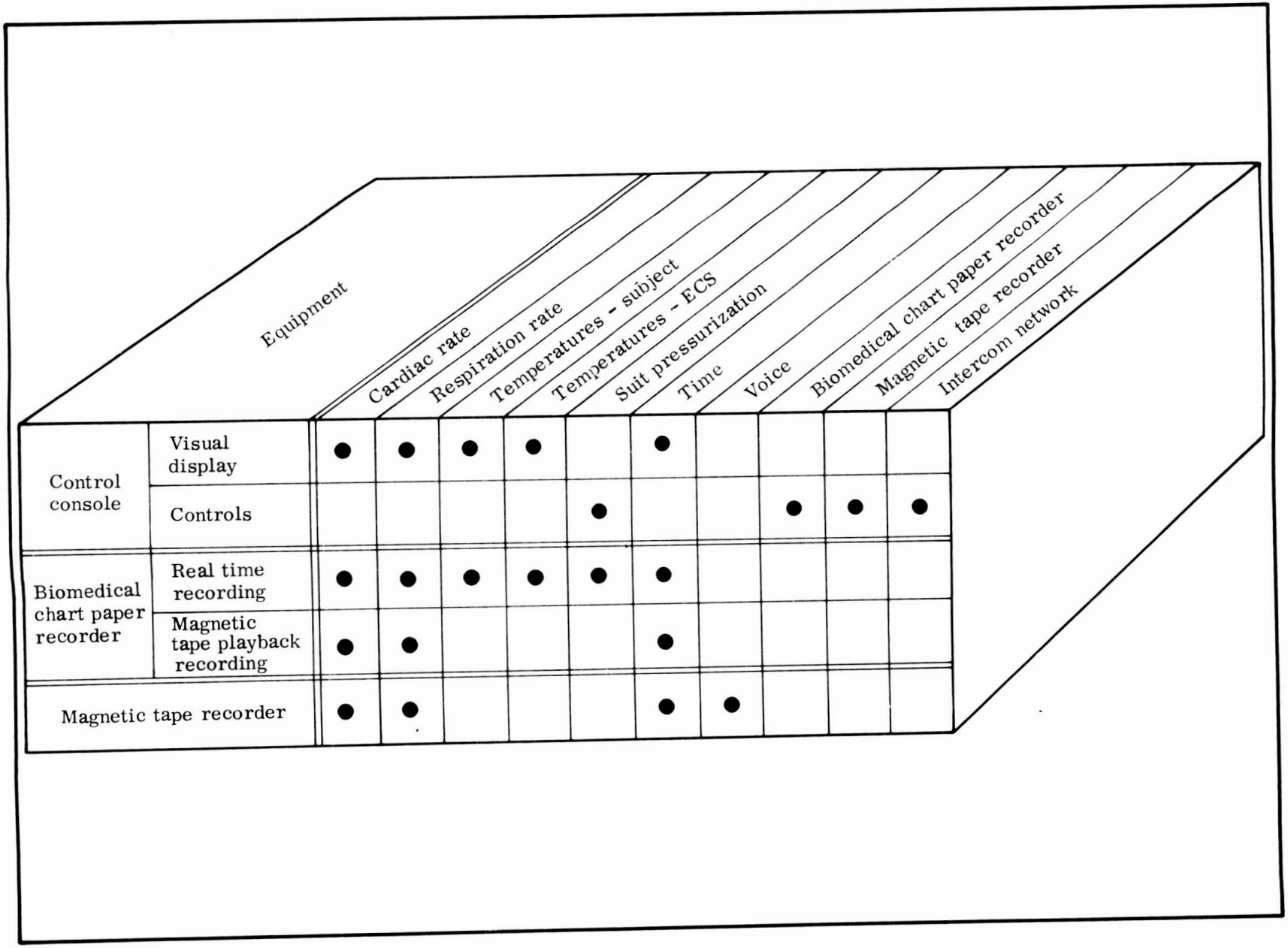

Figure 26. - Matrix of test control station operations

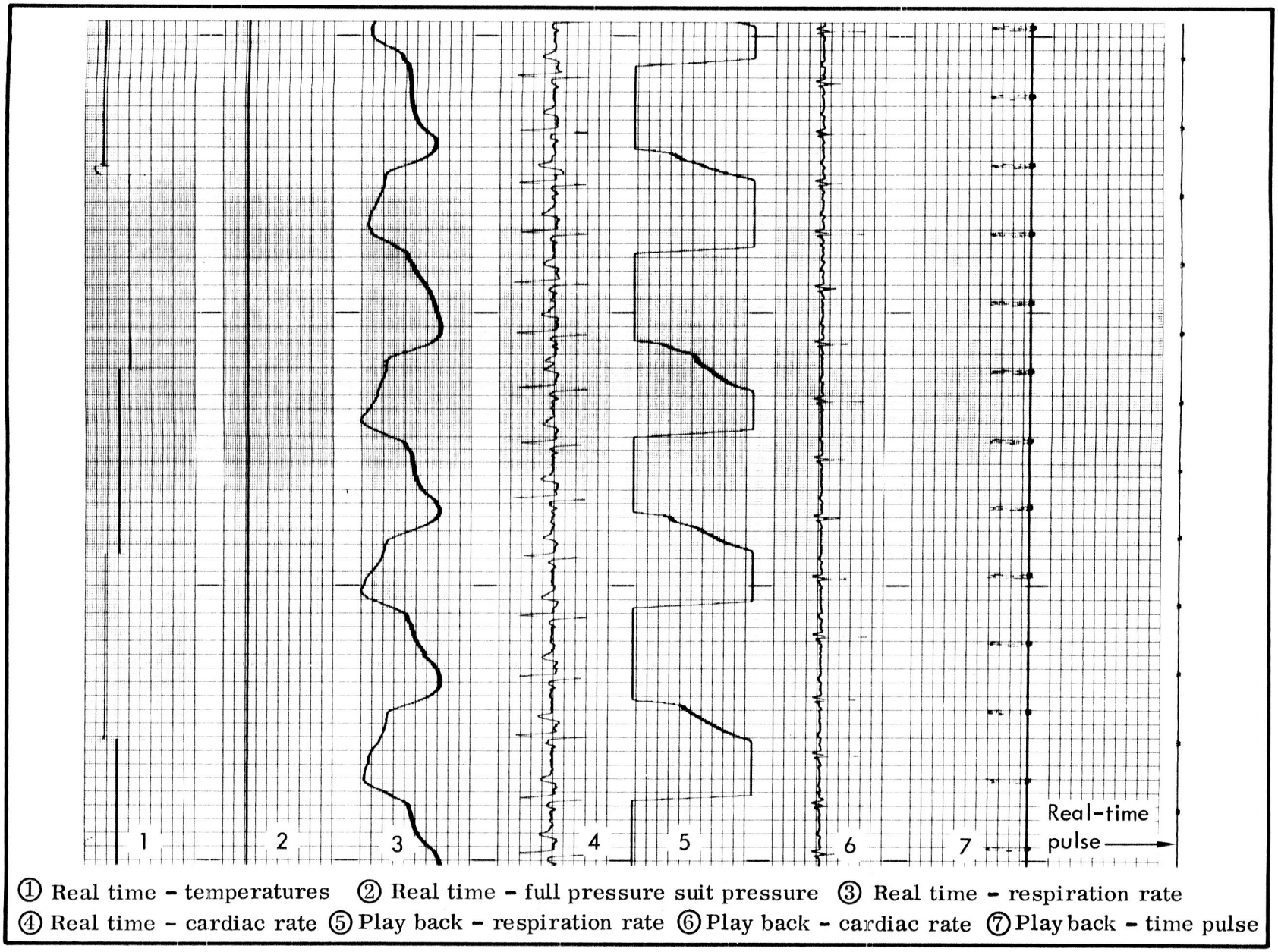

Figure 27- Analog history of recorded events

APPENDIX A

ANALYSIS OF ENVIRONMENTAL EFFECTS ON THE SENSING OF TEMPERATURES

A typical full bridge configuration shown in Figure A-1 was analyzed and its equations are presented below.

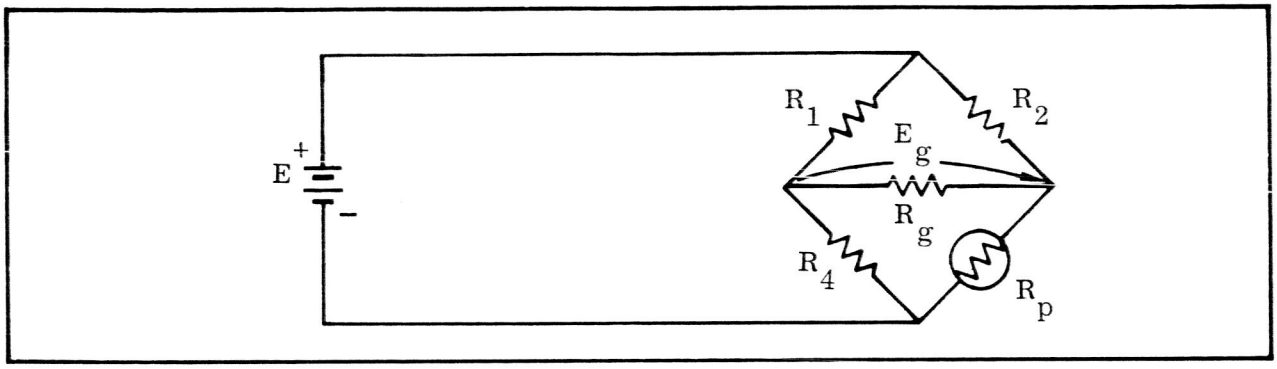

Figure A1. - Typical full bridge configuration

I. $R_p = R_{po} + \Delta R$

R_g = the detection arm (meter)
E_g = voltage across R_g
R_p = thermistor
R_{po} = value of R_p to null bridge
ΔR = deviation from R_{po}

II. $$E_g = \frac{E\,R_g \left[\frac{R_1}{R_1 + R_4}\right] \Delta R}{R_2\left[R_g + R_4 + \frac{R_4}{R_1}\,(R_2 + R_g)\right] + \Delta R\left[R_2 + R_g + \frac{R_1 R_4}{R_1 + R_4}\right]}$$

To determine the error in readings when the umbilical resistance contributed to R_p, the following ratio was used:

$$\% = \left[\frac{E_{g2}}{E_{g1}} - 1\right] 100$$

where:
E_{g1} = output voltage, umbilical not in circuit
E_{g2} = output voltage, umbilical in circuit

The following two cases were investigated where the umbilical cable was at an elevated temperature and where two different temperature ranges were being read:

	CASE I	CASE II
Umbilical temperature	110° F	110° F
Umbilical resistance	3 Ω	3 Ω
Bridge scale range	75° F - 95° F	90° F - 110° F
ΔR	900 Ω	600 Ω
	(2340-1450) Ω	(1650-1050) Ω
Circuit Parameters	CASE I	CASE II
	$R_1 = R_4$	$R_1 = R_4$
	$R_2 \approx 3.5R_1 \approx 3.5R_4$	$R_2 \approx 2R_1 \approx 2R_4$
	$R_g = 4.5R_1$	$R_g = 3.6R_1$
	$R_1 = 400\,\Omega$	$R_1 = 500\,\Omega$
Percent error introduced	0.24	0.4
Error over 20° F range	0.05° F	0.1° F

A graph of the resistance of thermistors as a function of temperature is shown in Figure A-2.

The effects of the thermistor lead length and of the umbilical at different temperatures are shown in Figure A-3.

A comparison of the globe thermometer and mercury bulb thermometer temperature readings is shown by the curves in Figure A-4.

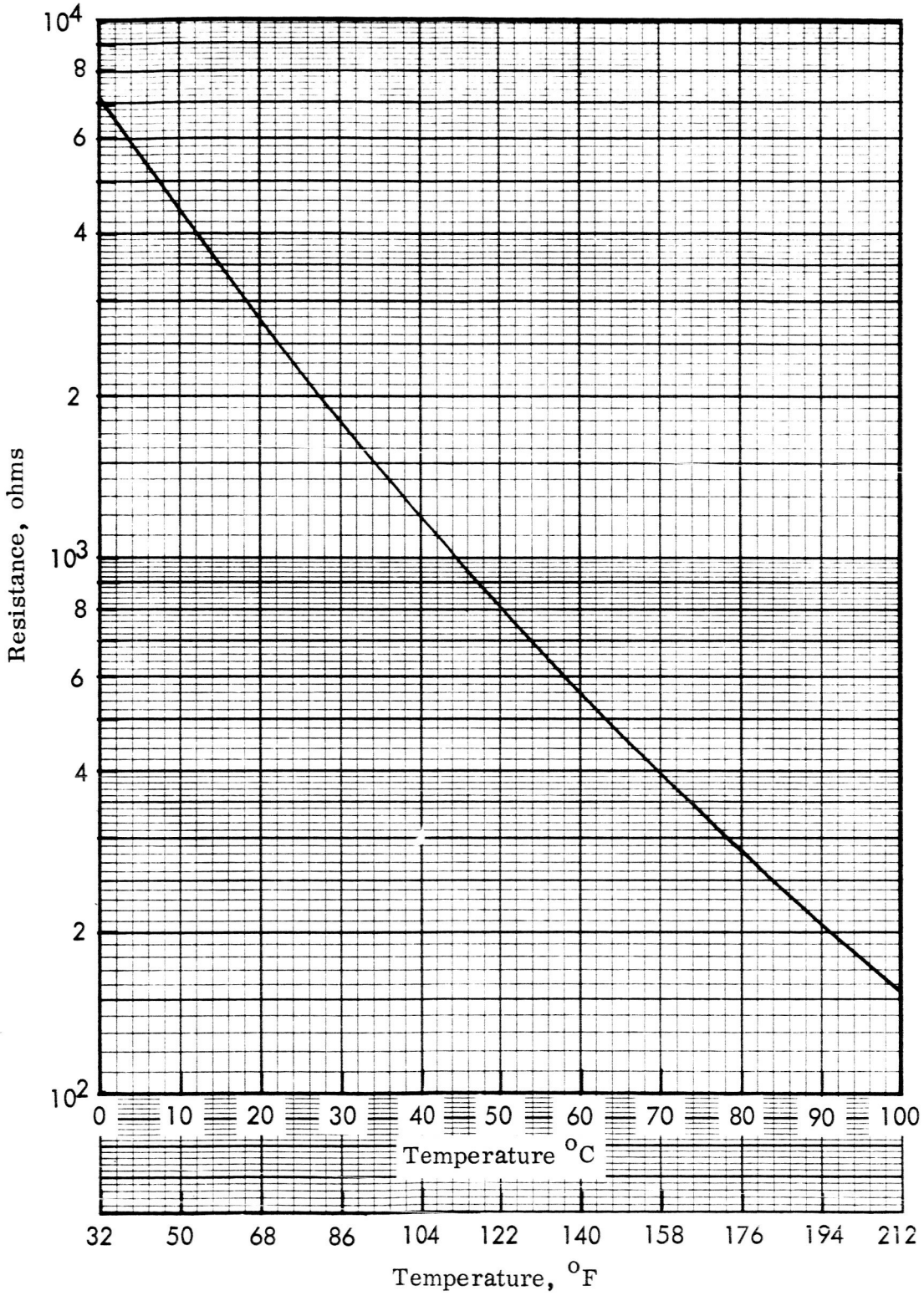

Figure A2, Resistance temperature characteristics of YSI 400 series thermistor probes (Ref. 1)

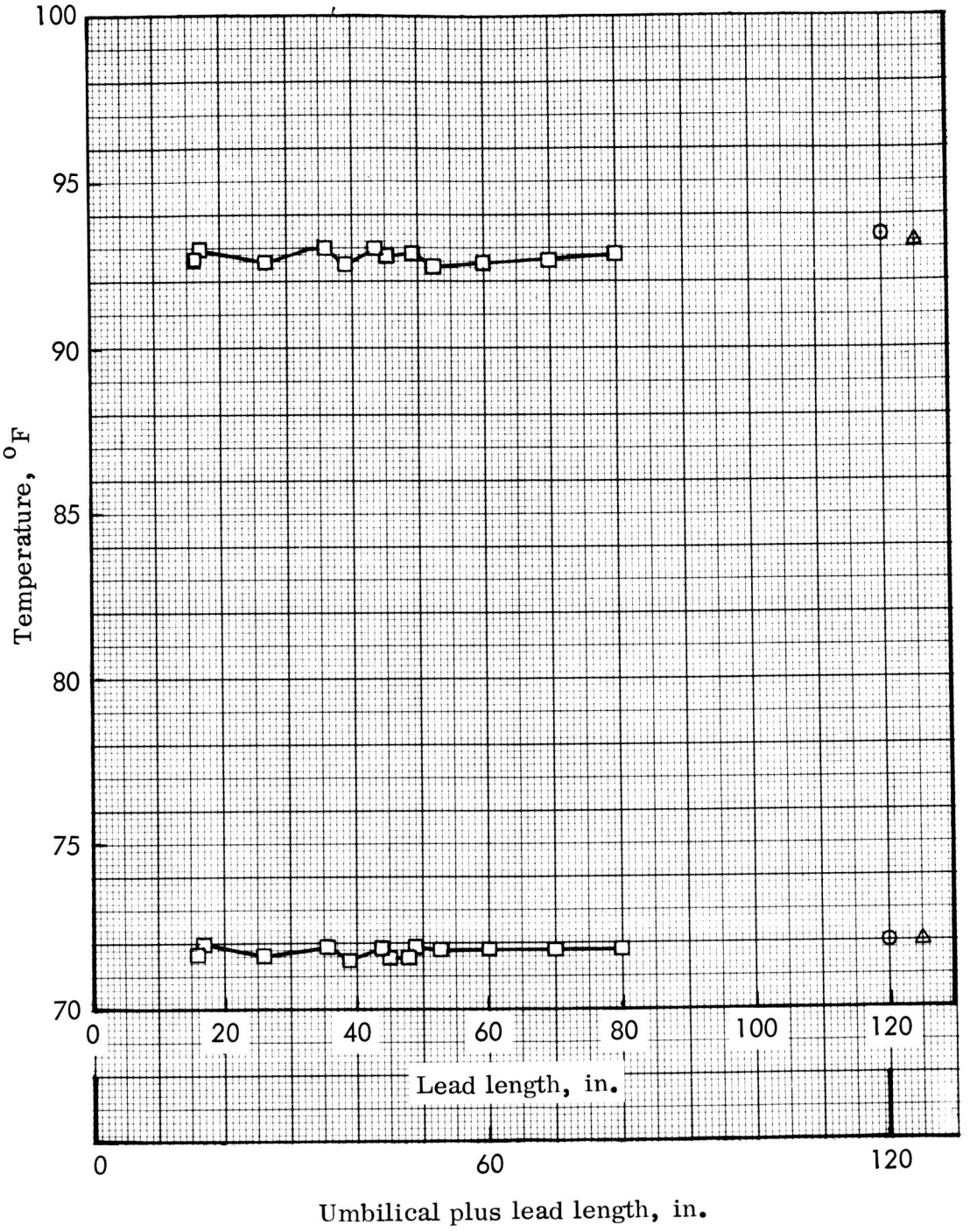

Figure A3 - Comparison of thermistor harness plus umbilical versus calibrating thermistor ⊙ or mercury bulb thermometer △ at two different temperatures. ⊡ = experimental data points

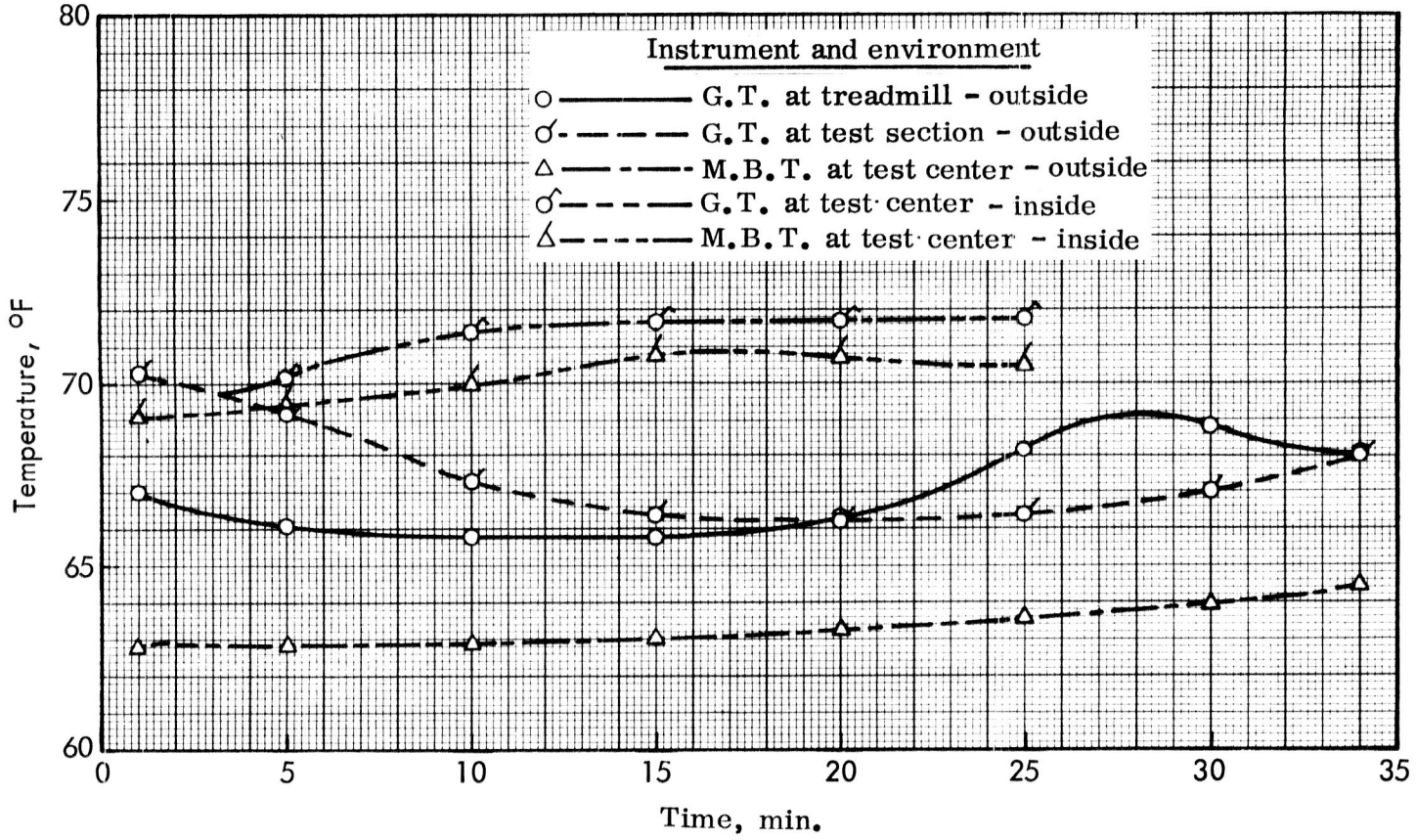

Figure A4, Fairied curves of globe thermometer versus mercury bulb thermometer temperature readings, at different environmental temperatures